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Problem-based learning in an on-line biotechnology course

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Problem-based learning in an on-line biotechnology course

by

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This is to certify that the doctoral dissertation of

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For the Major Program

DEDICATION

This dissertation is dedicated to the memory of

James R. "Sarge" Cheaney
1931 – 1997

whose love of learning and unquenchable thirst for knowledge
is the inspiration for my never-ending quest
to become not just a scholar,
but a sage.

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ABSTRACT

Problem-based learning (PBL) is a pedagogical tool that uses a "real world" problem or situation as a context for learning. PBL encourages student development of critical thinking skills, a high professional competency, problem-solving ability, knowledge acquisition, the ability to work productively as a team member and make decisions in unfamiliar situations, and the acquisition of skills that support self-directed life-long learning, metacognition, and adaptation to change. However, little research has focused on the use of PBL in on-line "virtual" classes. We conducted two studies exploring the use of PBL in an on-line biotechnology course. In the first study, ethical, legal, social, and human issues were used as a motivation for learning about DNA testing technologies, applications, and bioethical issues. In the second study, we combined PBL pedagogy with a rich multimedia environment of streaming video interviews, physical artifacts, and extensive links to articles and databases to create a multidimensional immersive PBL environment called "Robert's World". In "Robert's World", a man is determining whether to undergo a pre-symptomatic DNA test for an untreatable, incurable, fatal genetic disease for which he has a family history. In both studies, design and implementation issues of the on-line PBL environment are discussed, as are differences between on-line PBL and face-to-face PBL. Both studies provide evidence to suggest that PBL stimulates higher-order learning in students. However, in both studies, student performance on an exam testing acquisition of lower-order factual learning was lower for PBL students than for students who learned the same material through a traditional lecture-based approach. Possible reasons for this lower level of performance are explored. Student feedback expressed engagement with the issues and material covered, with reservations about some aspects of the PBL format, such as the lack of flexibility provided in cooperative learning. We conclude that on-line PBL is a powerful tool in helping to develop higher-order learning in students. The reasons for the decrease in student understanding of factual information are not entirely clear. However, there are certain circumstances unique to on-line classes to keep in mind when implementing on-line PBL. These are summarized in concluding recommendations.

CHAPTER 1

INTRODUCTION

Ever since the 1983 publication of *A Nation at Risk* (Gardner *et al.*, 1983), there has been widespread concern about the state of education in America's schools, both at the K–12 level and in higher education. Despite being the world's pre-eminent science superpower since the end of World War II, the United States in 2001 ranked 14th out of 31 industrialized nations in science literacy (defined as being "able to understand complex texts, evaluate information and build hypotheses, and draw on specialized knowledge") among high school students, far behind the leading nations of South Korea, Japan, and Finland, and just ahead of 15th-ranked Hungary (Lyne, 2001). A more recent study of American 15-year-olds ranked the United States 22nd out of 40 countries in scientific literacy (Margulis, 2005). The lack of understanding of the basic nature of science extends beyond schools to include the American public and policy makers on the local, state, and federal levels, as evidenced in the current debates over such topics as stem cell research, the purpose of the U.S. space program, and the teaching of "intelligent design" (Shipman, 2005). There is a perceived and real failure of educational institutions to sufficiently educate American students and the American people about science.

In medieval times, students learned by becoming apprentices of established artisans. Often, after an apprentice had learned the basic tools and techniques of the trade through a long process of training, an artisan might assign his or her apprentices with specific problems. For example, an apprentice blacksmith might be put to work making shoes for common draft horses. By solving these problems, the apprentice learned the general approach to problems that could be applied to nearly any situation that a journeyman might encounter. Apprenticeships still exist today, but modern formal higher education has been dominated by a Fordist model of treating students on a mass level through instructors imparting knowledge in large lecture halls in the hopes that students will absorb what is being told them (Campion and Renner, 1992). The justification for this "assembly line" model of education is simple: it is economically efficient, allowing the education of more students with fewer expensive instructors (Peters, 1988). The trend of teaching through lecturing is continuing as colleges and universities begin to take advantage of the revolution in electronic communications to make educational opportunities available to all members of the public, regardless of their distance from a campus. But are there alternatives in distance education from an instructor-centered format? After all, although lecture-based instruction, both in the face-to-face environment and in the distance education environment, excels in exposing students to factual information meant to be memorized (usually the night before an exam), it is much more difficult for students to learn the underlying nature of science – why scientists pursue science in the way that they do, and how that affects the interpretation of science that leads to hypotheses and theories being what they are – through the traditional lecture-based format. Is it possible for a virtual science class to present problems to students in such a way as to enhance their understanding, not only of technical facts, but also the ways in which scientists work and the nature of science? Is it possible for a virtual science class to stimulate the analysis, intellectual synthesis, creativity, and evaluation that is the quintessence of science? Can a virtual science class create an understanding in students of the ubiquitous ethical, legal, and social issues that have accompanied science ever since the days of Anaximander, Aristarchus, and Aristotle, the murder of Hypatia, and the destruction of the library at Alexandria (Sagan, 1980)?

Problem-based learning (PBL), first used in science in modern times at McMaster University, is an increasingly important part of education reform around the world. Like an apprenticeship, PBL exposes students to "real world" problems in a context that encourages student groups (PBL is usually conducted in cooperative learning groups) to apply factual knowledge in a way that broaches the philosophical and social implications that are so difficult to teach in a lecture-based environment. PBL has been used extensively in traditional face-to-face classroom environments through the biological sciences, including medicine (Barrows and Tamblyn, 1980), law (Clark, 1999a), pharmacology (Michel *et al.*, 2002), molecular biology (Ahern-Rindell, 1998), cell and tissue biology (Miyan, 2002), and general introductory biology courses (University of Delaware, 2005). Little is known about the use of PBL in the electronic-based distance-education "virtual classroom".

The objective of this study was to investigate the ways in which the power and versatility of the Internet gives instructors the potential to produce pedagogically- and scientifically-sound authentic learning experiences, such as PBL, and how a "virtual PBL" environment affects student learning, achievement of learning objectives for a unit concerning diagnosis of genetic diseases and pre-symptomatic DNA testing, and student attitudes about the efficacy of PBL. The study consists of two scholarly articles, one of which has been published (Cheaney and Ingebritsen, 2005), and one which will hopefully be published in the near future. The first article deals with the implementation of a text-based PBL unit, in which students are simply presented with the problem of a fictional man named

Robert with a family history of Huntington disease and links to resources which they may find helpful in helping him determine whether he should undergo pre-symptomatic DNA testing for a disease for which there is no effective treatment and no cure, and which inevitably leads to a premature and uncomfortable death. We determined whether the use of PBL compromised the acquisition of simple factual knowledge compared to a lecture-based presentation of the same unit; analyzed Bloom *et al.*'s (1956) "higher-order" learning of application, analysis, synthesis, and evaluation regarding Robert's dilemma; and reviewed student attitudes and recommendations concerning the text-based PBL unit.

The second article concerns the implementation of a multidimensional "immersive" PBL environment called "Robert's World". Robert's World is a virtual "city" that allows students to explore various sites relevant to Robert's dilemma, such as his home, workplace, health insurance company, genetic counselor's office, a genetic testing lab, and a library. These sites gives students access to video interviews with actors playing the parts of Robert and his family, and with experts in the fields of genetic counseling, genetic testing, health insurance, and bioethics. Students also have access to various physical artifacts from Robert's life (such as medical forms, insurance files, and laboratory records), and links to databases and articles concerning medical/genetic and legal information relevant to Robert's decision. As with the text-based PBL research, we determined student higher-order and lower-order learning and identified specific areas or topics where student learning was strongest and weakest. We also analyzed student attitudes and reactions to Robert's World, and determined advantages and disadvantages of the immersive PBL environment on student learning.

This study concludes with an analysis of how PBL in the on-line “virtual” environment affects student learning on both the higher-order and lower-order levels. Recommendations for how PBL can be utilized to maximize student learning and understanding and the fulfillment of course and unit objectives are also discussed.

CHAPTER 2

LITERATURE REVIEW

Science and Science Education: The Need for Reform

"Science" is derived from the Greek *scientia*, meaning "knowledge", but science is not just knowledge of any sort. Natural science is a procedure for the development and testing of hypotheses to explain how things in nature happen the way that they do (Kemerling, 2001). The goal of science is an asymptotic approach to the unattainable goal of the *ultima Thule* of ultimate "Truth" (Medawar, 1984). While ultimate certainty is unattainable in science (Kant, 1800/1974), science's great strength is its predictive capacity through deductive knowledge of facts and hypotheses to link those facts to the phenomenon in question. That is why, of the seven medieval liberal arts (grammar, logic, rhetoric, arithmetic, music, geometry, and astronomy), three (arithmetic, geometry, and astronomy) are squarely within the modern field of science, while one (logic) makes up the philosophical foundation of modern science (Lewis, 1964; Colish, 1997). The supply of scientific knowledge is central to the mission of the university, especially a university whose full name includes the words "of Science and Technology." Science is vital not only to the university's role in society, but also to society's well-being in the 21st Century. According to Jeremy Bernstein (1993; cited in Styer, 2002):

> It is a fact of modern life that all of us are confronted by decisions that have a significant technological component. It is crucial, in my view, that as many people as possible have enough technical background to be able to separate the purely technical aspects of these decisions from the political

> and moral ones. No one should be afraid of participating in making such decisions just because some "expert" says that there are technical factors involved that are beyond the layperson's understanding. Ignorance of science and technology is becoming the ultimate self-indulgent luxury.

However, surveys in the 1990s revealed a steep decline among the American public in understanding of the nature of science, and the basics of scientific knowledge. For instance, a 1995 survey indicated that less than half of Americans know that the Earth revolves around the Sun, and only 10% of Americans can describe a molecule beyond noting that it is small (*Science News*, 1996). A 1999 poll asked respondents to judge the veracity of the statement: "Ordinary tomatoes do not contain genes, while genetically modified ones do." Ten percent of Americans answered "true", while 45% responded with "don't know." Other countries fared even worse. When faced with the same question, Europeans responded with 35% answering "true" and 30% "don't know" (INRA (Europe)–ECOSA, 2000). Two-thirds of American students (and 1/3 of science majors) do not believe that an understanding of science is necessary for good citizenship (Deeds *et al.*, 1999). Nearly two-thirds of high school students believe in "a simplistic hierarchical relationship in which hypotheses becomes theories and theories become laws, depending on the amount of 'proof behind the idea'" (Ryan and Aikenhead, 1992). This last finding is similar to misconceptions reported in the 1970s (Mackay, 1971; Rubba and Andersen, 1978).

Many factors have been proposed to account for how the most highly-educated society in the world can be so scientifically illiterate. One factor that is often seen as a positive trend in increasing scientific literacy, and yet may ultimately be self-defeating, is the emphasis the popular media places on biotechnology, a phenomenon referred to by some as "genohype" (Caulfield, 2004). Overcommercialization of the research sector and increasing competition for grant funding puts pressure on researchers to justify their research in terms of short-term economic benefits. Attempts to translate these would-be benefits in layperson language for the media often leads to simplistic, unrealistic, and overly optimistic portrayals of science (Munby, 1976; Feynman, 1988; Medawar, 1990; Ransohoff and Ransohoff, 2001; Bubela and Caulfield, 2004), eroding public trust not only in scientists, but the nature of science itself (DeAngelis, 2000). The integrity of public science is also called into question when the return on investment is more important to a university than educational quality and when overcommercialization and collaboration with the private sector leads to a loss of openness and peer review due to proprietary concerns (Kevles, 2003). Bok (2003) suggests that this overcommercialization of research may even lead to corruption, as is the case with the overcommercialization of intercollegiate athletics.

Although the American public may be highly educated, many see science as a dogmatic quasi-religion dominated by trivia, rather than a search for mechanistic models that explain the natural world. According to many cognitive psychologists, the public's disconnect from modern science is due to an educational background which does not provide students with essential contextual features that enable students to understand information (Chi *et al.*, 1981), such as an understanding of the nature of, history, or philosophy of science, or how science should be perceived (for instance, the difference between statistical significance and "proof"). Many Americans cannot apply scientific principles in a scientific manner rather than a pseudoscientific or teleological manner (Rudolph and Stewart, 1998; Shipman, 2005). Learning is too far removed from "real world" purpose (Deeds *et al.*, 1999). As a result, efforts by universities to create citizens who can apply the philosophy of science to solving problems in the "real world" are failing (Gibbons, 1994).

One example of the disconnect between science education and the "real world" is archaic illustrations that continue to be used because of inertia, even if invalidated. They make a mockery of scientific literacy among non-scientists. An example of this is made by Gould's (1988) criticism of the ubiquitous comparison in size that is made between *Eohippus* and the fox terrier. Not only have scientists known for quite some time that *Eohippus* was considerably larger than a fox terrier (invalidating this archaic simile), but, as Gould (1988) points out, how many Americans even know what a fox terrier is? Why does this comparison, which is meaningless as well as invalid, continue to be made? Because it was made by British evolutionary biologists in the 19th Century and no one bothered to check its validity or utility. "Through time, one author after another simply repeated the inept comparison and continued a tradition [of] making many science texts virtual clones of each other on this and countless other points" (McComas, 1998).

Many educators believe that the most effective focus of science education is on the holistic understanding of how science works (experimentalism) and how it affects and is affected by societal concerns, including ethical, legal, and social aspects of developments in the applied sciences and technology that have an immediate impact on society. This theory of science education implicitly emphasizes the development of the thinking process, and a conscious awareness of this process, as opposed to substantive knowledge of details that must be memorized by rote (Schwab, 1974; Caprio *et al.*, 1989; McIntosh and Caprio, 1990; Steen, 1991; American Association for the Advancement of Science, 1993; Driscoll, 1994). However, traditional science classes have emphasized substantive knowledge (the emphasis of rote facts), claiming that it represents positivist reality as revealed by excessive rationalism. These classes are structured around memorizing the details of the subject matter itself (such as the differences between Zygomycota, Ascomycota, and Basidiomycota), rather than taking into account student-centered concerns such as variations in learning styles (Welch *et al.*, 1981; however, the dangers of taking the importance of learning styles to an extreme is argued by Willingham, 2004). In science, there is a significant amount of substantive knowledge that must serve as a foundation for student understanding to be constructed upon (for instance, biotechnology is built upon the foundation of molecular biology, which is built upon the foundation of biochemistry and cell theory, and so forth) (Ahern-Rindell, 1998). Nevertheless, the over-emphasis of rote memorization is thought to have contributed to the perceived and real failure of science education in the United States to sufficiently educate American students (Stake and Easley, 1978; Stukus and Lennox, 1995).

For instance, if a scientist simply states "the Earth is 4.5 billion years old," citing the authority of a textbook, a creationist can easily counter "the Earth is 6,000 years old," citing an even higher authority. Science teaching must be integrated with an understanding of deductive logic based on experimentalism, achieved through lab work, problem solving, simulations, or literature review, and the limitations of all of these (Hand *et al.*, 1999). Science is always a "minds-on" enterprise (Ryan and Aikenhead, 1992; Styer, 2002). Talking about science as a list of facts does not satisfy a student's intellectual curiosity any more "than a beautiful photograph of a Thanksgiving turkey is likely to satisfy a hungry person" (Styer, 2002). Indeed, knowledge of scientific facts may not be vital for obtaining science literacy. It is the understanding of the nature of science and the application of that nature to everyday problems (such as public policy issues with political relevance ranging from stem cell research to global warming to nuclear energy to space exploration) that are prerequisites for being scientifically literate and for practicing quality citizenship (Cobern *et al.*, 1995; Hurd, 1998; McComas *et al.*, 1998; Hand *et al.*, 1999).

Problem-Based Learning (PBL)

What is PBL?

Problem-based learning (PBL), also known as case-based learning, is an increasingly integral part of education reform in the United States and around the world. The essence of PBL can be summarized as the use of a "real world" problem or situation as a context for learning (Morgan, 1983; Barrows, 1985; Boud, 1985; Herreid, 1994; Duch, 1995; Domin, 1999; Michel *et al.*, 2002). The purpose of PBL is to increase education's relevance to the perceived needs of the professional community, to increase the development of critical thinking, to engage student interest, and to increase the problem-solving abilities of graduates, with the use of situations or problems presented in class that resemble reality (Boud, 1985; Boud and Feletti, 1991; Banerjee, 1994; Herreid, 1994; Ostwald and Chen, 1994; Shannon and Brine, 1994; Michel *et al.*, 2002). PBL is a student-centered approach to learning, facilitating the construction of a conceptual network of knowledge in students, which can be subsequently applied in a wide range of practical settings (Creedy *et al.*, 1992; Creedy and Hand, 1994; Cruickshank and Olander, 2002). In many cases, the realistic problems used in PBL studies may not have a right or wrong answer.

PBL is conducted by introducing students to situations or problems that resemble reality. It can be used to make the construction of a conceptual network possible, increasing the probability of retention of the general objectives of the problem-based unit. PBL works through five cognitive areas to stimulate learning:

1) activation of students' prior knowledge
2) elaboration of prior knowledge through cooperative discussions
3) restructuring of knowledge to fit the problem presented; construction of an appropriate semantic network through internal discourse
4) learning in the scaffolding context of a real-world problem
5) emergence of epistemic curiosity due to relevance of problem

(Schmidt, 1993)

In the PBL environment, students should be allowed to analyze the problem in its own and the student's contexts and environments (Coles, 1990, 1991). Students must construct a method to arrive at a detailed analysis, if not a final conclusion (this process is sometimes referred to as "situation-based learning"; Dockett and Tegel, 1993; Russell *et al.*, 1994). While the specifics of how the students will arrive at an analysis must be determined by the students themselves based on their own perceptions of what information is needed, such as how to divide the labor, the instructor may provide guidance in the form of a structured decision-making process. A gestalt impression is certainly a valid way to arrive at a good decision (Wertheimer, 1925), but it is difficult to defend a decision that is not arrived at in a very logical and careful fashion (Maner, 2002). Care must be taken to ensure that students are not forced to follow one particular logical path to a predetermined conclusion (sometimes referred to as "solution-based learning" (Cowdroy, 1994); however, for an opposing viewpoint on the importance of actually *solving* the problem, see de Shazer, 1985). In PBL, the focus is on the *process*, not the *product* (Patel *et al.*, 1991; Margetson, 1994; Shannon and Brine, 1994).

Learning objectives in PBL situations include the development of critical thinking skills, development of a high professional competency, development of problem solving abilities, acquisition of knowledge, development of the ability to work productively as a team member and make decisions in unfamiliar situations, and acquisition of skills that support self-directed life-long learning, self-evaluation, and adaptation to change (Engel, 1991; Albanese and Mitchell, 1993; Ryan and Quinn, 1994). These learning objectives are typically achieved when certain conditions exist with regards to the problem presented, and when these conditions can be remedied by the design of the PBL assignment. The four conditions which need to be fulfilled by the PBL design are:

1) The student should be unhappy with the current state of his or her current knowledge to solve the problem.
2) The new concepts should be intelligible, plausible, and understandable.
3) The new concepts should be immediately applicable to the problem.
4) The new concepts should be *more* applicable to the problem than the learner's previous knowledge.

(Gunstone and Northfield, 1988)

PBL has the advantages of providing a forum where a design process can be used to arrive at a solution, generating the need to look at other study disciplines that contribute to the problem-solving process (Banerjee, 1994; English *et* al., 1994; Ostwald and Chen, 1994). The PBL environment is also very flexible in allowing any depth of knowledge that the instructor desires. In some cases, students can also enter and exit the problem at any level without any loss of understanding or without needing *a priori* knowledge base (Banerjee, 1994), although the withdrawal of students can create problems in a cooperative learning group. PBL promotes studying for meaning and long-term understanding rather than studying for short-term recall on an exam (Newble and Clarke, 1986), though results in the literature for overall knowledge acquisition through PBL are mixed (reviewed in Norman and Schmidt, 1992; Albanese and Mitchell, 1993). PBL also provides an excellent connection between the traditional college educational setting and continuing and extended education (Knowles, 1980; Trevitt and Sachse-Åkerlind, 1994; Vásquez de Velasco de la Puente and Angulo Mendívil, 1994). Finally, in the nature of its interactive approach between thinking, discussion, and searching for more information, PBL mimics the approach that many people usually take to problems in real life (Herreid, 1994).

PBL assignments typically occur in several stages:

1) The problem is encountered first, before any formal study has been conducted.
2) The problem is presented to students in the same way that it would be faced in reality.
3) Students work with the problem in such a way that permits their reasoning and application of knowledge to be challenged and assessed.
4) Needed areas of learning are identified by the students and used as a guide to individualized study.
5) The skills and knowledge acquired are applied reiteratively to the original problem.
6) The learning that has occurred is integrated into the students' existing knowledge and skills.

(Barrows and Tamblyn, 1980; Barrows, 1986; Duch, 1995)

The role of the instructor is quite different between PBL and the more-traditional lecture-based instructor-centered environment. In classical PBL, the instructor interferes as little as possible in the group's discussions about their science and research (although there is still an extensive role for the instructor in helping students locate sources for research, monitoring their progress through authentic learning activities, and handling interpersonal disputes in dysfunctional groups in an even-handed manner). Students are often initially uneasy with a non-interfering-in-course-material instructor since they are used to being told what is right and what is wrong, but usually they eventually grow more comfortable with the situation as they assume responsibility for their own learning (Michel *et al.*, 2002). However, a greater depth of understanding is achieved with an interactive facilitator who helps steer the students towards successful solving of the problem than with a completely passive instructor (M. G. Moore, 1993; Mierson, 1998; Miyan, 2002). The identity of who is leading the PBL group also has an impact on PBL outcomes. Steele *et al.* (2000) found that, in medical schools, peer-led student groups tended to take shortcuts that might undermine some of the intended goals of PBL, and that learning outcomes are higher in PBL classes that have a tenured faculty member as the instructor than in those in which the instructor is a post-doctoral fellow.

History of PBL

PBL is not a new idea. It has a long and distinguished history. In the 5th Century B.C.E., the Chinese philosopher Lao-Tse wrote, "If you tell me, I will listen. If you show me, I will see. But if you let me experience, I will learn" (cited in Clark, 1999b). Kung Fu-Tse (better known as Confucius) followed by using a method that closely resembles PBL. A member of the study group would present a paradox, which would be in the form of a parable. The study group would then discuss it and explore possible resolutions (Clark, 1999b).

In India, a teacher (*guru*) would debate philosophy with his disciples (*sishya*) using a problem, query, or puzzle that the group wanted to solve. The students themselves determined what was to be learned and how it was to be learned. The *guru* facilitated the students' learning, both as a repository of knowledge, and also in introducing metacognition skills, which would teach the students *how* to learn (Boud, 1985). The effectiveness of PBL can be seen in the rich contributions made by Indian philosophers and scientists during this era (Banerjee, 1994). A very similar PBL-like strategy was used in Celtic Europe for the training of druids, whose formal education took more than 20 years (Ross, 1995).

In classical history, the teacher who perfected the art of teaching through the investigation of problems was the Athenian philosopher Socrates (470-399 B.C.E.). It should be noted, however, that Socrates himself never recorded any of his teaching methods. These methods were recorded by Socrates' student Plato, who attributed them to his old teacher, and Plato's student Aristotle. Aristotle later became the teacher of Alexander, and through Alexander, Socrates' ideas became the method of choice for learning philosophy throughout the known world.

The Socratic method begins with the process of *elenchus*, which is defined as "a prolonged cross-examination which refutes the opponent's original thesis by getting him to draw from it, by means of a series of questions and answers, a consequence that contradicts it" (Vlastos, 1994). The students and instructor then leisurely discussed the problem (usually at a *symposium*, an activity which is best described as a "class" that includes copious amounts of wine, musicians, dancers, and philosophical debate). A student often began this discussion by expressing his (all of Socrates' students were male) raw ideas, but had to re-examine his ideas (or reinforce them by thinking about it from a different angle) in response to his classmates' and instructor's questions, a process called *psychagogia* (Stuckey, 2004). At the end of the discussion, he arrived at an analysis that was either similar to or quite different from his inchoate thoughts on the matter at the beginning of the *symposium*. Whatever the outcome, he certainly had formulated theories that were richer than those he began with. Socrates himself underwent the same process as an instructor, and demonstrated a willingness to change his opinion should the explanation be logical. The instructor learned from his students as he challenged them with questions that either destroyed or strengthened their arguments. And unlike more-traditional forms of learning, students were not compelled to blindly accept the reasoning of the instructor (Orig, n.d.).

For instance, Plato tells the story about a debate between Socrates and Protagoras on the problem of whether excellence can be taught. Socrates admitted to Protagoras, "I don't consider that excellence can be taught. But when I hear the suggestion coming from you, I begin to have second thoughts and to think that you must have a point" (Plato, 380 B.C.E./1986). As the discussion progressed, using examples from Greek mythology, Socrates developed the idea that everything was a kind of knowledge, and excellence, therefore, could indeed be taught. Protagoras, meanwhile, resolutely argued that excellence was not knowledge, and therefore Protagoras' hypothesis gradually became that excellence could not be taught. By the end of the *symposium*, Socrates and Protagoras had both developed opinions that were the opposite of the hypotheses they had started with, and were once again at odds (Orig, n.d.).

Not all students were well-suited to Socrates' method for examining problems, though, and Socrates developed a negative as well as a positive reputation in Athens. In a dialogue with Socrates, the slave Meno said, "Socrates, even before I met you they told me that in plain truth you are a perplexed man yourself and reduce others to perplexity [*aporia*]. At this moment I feel you are exercising magic and witchcraft upon me and positively laying me under your spell until I am just a mass of helplessness. My mind and my lips are literally numb, and I have nothing to reply to you" (Stuckey, 2004).

According to Plato, Socrates remained loyal to the rhetoric of *elenchus* even when faced with the ultimate problem, that of his impending execution. When Crito offered to bail him out of prison, Socrates said, "Let us examine this question together, my friend, and if you can contradict anything that I say, do so, and I shall be persuaded" (Plato, 380 B.C.E./1986). Even with his own life at stake, he opened himself up to refutation while going through the process of refuting somebody else, always in search of the *ultima Thule* of truth. Socrates concluded that an injustice could not be offset by another injustice. And so he said, "I am still what I have always been – a man who will accept no argument but that which on reflection I find to be truest" (Plato, 380 B.C.E./1986). In his case, that *ultima Thule* of truth that this problem forced him to required Socrates to drink the hemlock he had been sentenced to (Orig, n.d.).

As a product of the Hellenistic philosophical tradition inherited by Rome, the Bible is replete with parables that bear a striking resemblance to PBL problems. However, as a religious book that seeks to instill a particular sense of morality, the Bible always gives a "correct" answer in the end, unlike many modern PBL problems which have no "right" or "wrong" answer (although one can easily imagine Jesus pausing in his discussion to give the disciples time to come up with their own solutions to, for example, the puzzle of the faithful steward). Storr (1997) argues that religious figures such as Jesus, Muhammad, and Buddha can be specifically termed *gurus* using the Indian definition in the manner they taught their followers.

Modern PBL in the United States was born as the "case method" developed by Christopher Langdell and his colleagues at the Harvard Law School in the 1880s (Fraser, 1931). In law, the case method consists of studying real court cases and actual court opinions, rather than legal philosophies and law books. Clark (1999a) describes the classical Harvard case method this way: "Although the case method does not actually provide real experiences, it is personal as it puts the burden of thinking on the learners and arouses their interest by making them active participants." Although the reactions to Langdell's methods by both colleagues and students were at first critical, his students graduated from law school better-prepared for employment than their classmates who had been taught by more-traditional methods. By the 1920s, law schools all over the United States were using the case method (Stuckey, 2004).

PBL was developed as a formal educational concept by John Evans and his colleagues at the Faculty of Health Sciences at McMaster University in Hamilton, Ontario, in 1969 (Spaulding, 1991). PBL integrates student knowledge across subject boundaries (holistic education) and helps students to develop problem-solving skills, which is a large part of what being a physician is all about. The objectives of PBL in medicine are the structuring of knowledge in clinical contexts, and the development of clinical reasoning, self-directed learning skills, and intrinsic motivation (Barrows and Tamblyn, 1980).

Since 1969, PBL has been adopted by hundreds of instructors for their classes in dozens of disciplines at scores of universities around the world. PBL is used for at least part of the curriculum at 80% of medical schools (Jones, 1996; cited in Orig, n.d.). While PBL has been most readily adopted in professional and pre-professional courses, it also has been adopted in lower-level undergraduate classes traditionally used for imparting basic information. In the biological sciences, examples of this include molecular biology at Weber State University (Ahern-Rindell, 1998), cell and tissue biology courses at the University of Manchester (Miyan, 2002), and introductory biology courses at the University of Delaware (http://www.udel.edu/pbl/). As of September 2005, a number of on-line directories and databases existed to help direct instructors to ideas, problems, concerns, and networks concerned with PBL, including:

- Maastricht University (http://www.unimaas.nl/pbl/)
- Univ. of Brighton PBL Directory (http://interact.bton.ac.uk/pbl/index.php)
- Queen's University (http://meds.queensu.ca/medicine/pbl/pblhome.htm)
- University of Colorado Center for Instructional Support (http://www.uchsc.edu/CIS/PBL.html)

- Central Queensland University (http://pbl.cqu.edu.au/)
- University of Delaware (http://www.udel.edu/pbl/others.html)

Constructivism and PBL

Philosophy of Constructivism

> Perhaps we need to be much more radical in the explanatory hypotheses considered than we have allowed ourselves to be heretofore. Possibly the world of external facts is much more fertile and plastic than we have ventured to suppose; it may be that all these cosmologies and many more analyses and classifications are genuine ways of arranging what nature offers to our understanding, and that the main condition determining our selection between them is something in us rather than something in the external world.
> – E. A. Burtt (1924; cited in Berman, 1981/1989, p. 127)

Constructivism is a Kantian philosophy (also heavily influenced by Descartes) which views knowledge as something the learner must uniquely construct for and by himself or herself in order to have a personal understanding of their own interaction with their environment (Kant, 1800/1974; Dewey, 1916, 1929; von Glasersfeld, 1974; Hilgard and Bower, 1975; Ryle, 1975; Blais, 1988; Caprio, 1994). Dewey (1938) defined an educational experience as a "transaction taking place between an individual and what, at the time, constitutes his environment" (p. 43). The roots of constructivism can be traced back to Socrates' assertion (once again, recorded by Plato who attributed it to Socrates) that the conditions for learning are within the cognition of the individual (Kanuka and Anderson, 1999). Kant (1800/1974) and later theorists developed this insight further as a philosophical foundation for perceptive reality, based on three fundamental questions (Jonassen, 1996; Hofer and Pintrich, 1997):

- What does it mean to know something?
- How do we come to know it?
- How does this knowledge influence our thinking processes?

There are four major philosophical strands of constructivism. Each offers a unique perspective on reality, a learner's perception of reality, and the learner's social interrelationships and how those affect a learner's perception of reality (Table 1).

1) Cognitive constructivism. This strand of constructivist philosophy is also known as critical constructivism (Kanuka and Anderson, 1998), cognitive dissonance (Festinger, 1957; Carson *et al.*, 1988), cognitive restructuring (Belkin, 1982), and perspective transformation (Mezirow, 1990). Based on the pioneering work of Swiss educational psychologist Jean Piaget, cognitive constructivism assumes that knowledge is constructed through a reasoned integration of internal contradictions generated by interactions with an objective environment. Knowledge is continually evolving and even re-inventing itself to reconcile new experiences with past experiences (Piaget, 1970; Piaget and Inhelder, 1973; Brainerd, 1978; Carver and Scheier, 1988). This new understanding can be achieved by *assimilation* into a pre-existing view, or *accommodation* into a *de novo* understanding (Kanuka and Anderson, 1999). Cognitive constructivism holds that there is an external reality – that nature is objective – and that the evolution of one's cognition through the reconciliation of these contradictions is an attempt to understand, though understanding the ultimate truth can never be achieved (Kelly, 1955; Medawar, 1984; Young, 1997). While cognitive constructivism does not deny the importance of social interaction, the focus is the evolution of the thought process within the individual learner's mind (Kanuka and Anderson, 1999).

The implications of debating these contradictions are similar to that of Socratic *elenchus*. Perkins (1991) says that cognitive constructivist pedagogy "aims to confront the learner with situations that make the inherent inconsistencies in the learners' naïve model

TABLE 1. Summary of constructivist philosophies.

Constructivist philosophy	Cognitive	Radical	Situated	Co-constructivism
Pioneering theorist (date of classic book)	Piaget (1970)	von Glasersfeld (1974)	Mannheim (1929/1936)	Vygotsky (1930/1978) Vygotsky (1934/1962)
Reality of external/ physical environment	objective existence	unknown and irrelevant	imposed from within context	imposed by language upon physical existence
Place of intellectual construction	individual	individual	societal, but understanding of the resulting construction or its implications is individual	sociocultural development of language
Process of intellectual construction	assimilation or accommodation of new experiences	built upon unique perceptions	interpretation of repeating social patterns by flexibly attacking problem from many possible directions	semantic debate and argumentation
Result of intellectual construction	integration of contradictions into understanding	context-dependent modification of experiences	recognition of multi-universe	meaning through semantic negotiation
Social interaction during intellectual construction	*elenchus* of experience	understanding and tolerance of others' realities	acceptance of other realities; internal *elenchus* of understanding within individual's mind	*elenchus* of language
Pedagogical tools	PBL; debates; individual/group summarizing	PBL; cognitive apprenticeship; emphasis on metacognition	PBL	PBL; discussion groups; Socratic dialogue; brainstorming; debriefing
Impact on PBL	classical PBL as defined in most of the literature to date	more focus on teaching students *how* to learn (*e.g.* how to define problems, how to question, *etc.*); instructor in this capacity acts more as a guide or coach rather than catalyst; responsibility for learning material lies with student	cooperative groups vital (cannot be pursued by individual PBL); focus is on building relationships between their own understanding and "devil's advocate" positions, so that group understanding can be seen from many angles	classical PBL as defined in most of the literature to date (the difference with cognitive is *what* is being constructed and *how*; the implications for PBL practice are the same as for cognitive)

plain and challenge the learners either to construct better models or at least to ponder the merits of alternative models presented by the teacher" (p. 19). The key from the instructor's point of view is to maintain and capitalize on the inconsistencies between the learners' current understanding and the new experiences or logic they encounter (Clough, 1997, 2000). These inconsistencies yield an intellectual disequilibrium in the students' minds, and perhaps conflict or puzzlement if differing student assumptions from different students come into play. Through argumentation (Kuhn, 1991), even if the argumentation takes the form of "devil's advocate" arguments, new knowledge is necessarily constructed on the scaffolding of these inconsistencies (Tobias, 1991). Resolution of these inconsistencies should be an intellectually pleasurable event for the student (Feynman, 1988). Pleasure stimulates neurons to release cyclic-AMP release element binding protein (CREB), which strengthen neural synapses, strengthening memories of whatever caused the pleasurable event (Fields, 2005). In this case, resolution of the inconsistencies is remembered. The instructor's role is that of catalyst. Learning activities that are appropriate using this model are PBL, debates, individual and group summarizing, and team teaching (Kanuka and Anderson, 1999).

2) Radical constructivism. The fundamental assumption of radical constructivism is reality itself is a function of the workings of our cognitive structure, ultimately personal, and can not be truly shared in experience (Suchman, 1987; Maturana, 1991). Knowledge is constructed based on our experiences in a particular context or environment (Winograd and Flores, 1986; Honebein *et al.*, 1993), and since no two people ever have identical experiences in identical environments, no two people will ever have the same understanding of reality (Jonassen, 1991). Since one cannot compare one's assumptions about reality with others, one can never know for sure what exists in reality (Kanuka and Anderson, 1999). Thus, Jonassen (1990) claims, "Reality is to a degree whatever the knower conceives it to be...our experiences determine our reality" (pp. 32, 34). Cooper (1993) claims, "Constructivists...state that personal experience determines reality, not the other way around" (p. 16).

How is radical constructivism possible in science, which has always assumed that the physical world that it studies is real? Radical constructivism is agnostic on the question of the actual existence of the physical world; its focus is on the learner's *perception* of reality. Perception occurs when the brain takes a signal, compares it with past experiences, and categorizes it, in the process altering its own categorization process, due to selection that occurs in the brain of the recursive neuronal loops that strengthen synaptic connections via the production of CREB (Edelman, 1989; Fields, 2005). "Primary consciousness may thus be briefly described as the result of the ongoing discrimination of present perceptual categorizations by a value-dominated self-nonself memory...If no comparison took place between value and past categorizations to form a special memory, consciousness would not appear" (Edelman, 1989, p. 102). In other words, cognition consists of "never-ending recursive processes of computation" (von Förster, 1984, p. 48) that has the value of reducing input (through re-organization into various dimensions, mnemonics, and chunks) into a manageable amount of data that can be analyzed by the brain (Miller, 1956). Because of the genotypic variance present in every individual and the unique experiences encountered by each individual, this "neural Darwinism" acts differently in each individual, making each perception of reality unique (Edelman, 1989). Not that this relativity of reality is necessarily a good thing, as it makes brainwashing and propaganda, self-fulfilling prophecies, and fraudulent "recovered memories" possible (reviewed in Watzlawick, 1984).

A problem in science that many radical constructivists emphasize is the fact that observation of a phenomenon can change the nature of the phenomenon being observed. This is classically illustrated by Schrödinger's Cat paradox in which one attempts to determine whether the cat is alive or dead, by opening the box to see the cat's activity (or lack thereof). Unfortunately, the act of opening the box kills the cat (Schrödinger, 1935). In this case, the attempt to measure the results of the experiment have changed the parameters of the experiment; the science has created its own results that have less to do with the experiment itself and more to do with the methods of observation. Indeed, quantum physicists have long known that manipulations of matter (such as those that occur during measurements) can have instantaneous effects not just nearby but anywhere in the universe, a phenomenon known as non-locality (Einstein *et al.*, 1935; Bell, 1964; Aspect *et al.*, 1982). Ironically, Schrödinger (1935), Einstein *et al.* (1935), and Bell (1964) in their papers were using Socratic *elenchus* to try to disprove the "Copenhagen Model" of quantum physics (advocated by Copenhagen native Niels Bohr, and epitomized by Heisenberg's Uncertainty Principle) by showing how "ridiculous" some of the Copenhagen Model's conclusions could be. These papers have become classics illustrating the validity of the Copenhagen Model. Quantum physics is such a strange field that *elenchus* often does not work if one is using conclusions simply on the basis that they appear to be impossible in the macroscopic world. Like Socrates and Protagoras, exploring the paradoxes of the Copenhagen Model compelled John Bell to change his mind and become its advocate following the publication of his 1964 paper (Zanghì and Tumulka, 2003).

The problem of changing experimental parameters in the process of observing is a common dilemma in the biological sciences. For instance, did Jane Goodall observe chimpanzee behavior as it normally is, or did she observe chimpanzee behavior as it is when there is a human visitor in the troop? Science can be pursued effectively only when scientists agree beforehand on an extensive set of ground rules that all scientists must play by (Ennis, 1979; Berman, 1981/1989). The best-known example of scientists agreeing upon a ground rule to reduce subjectivity in an experiment is the use of control groups. Experimental data by itself is meaningless; it is the *comparison* (subject to statistical analysis and interpretation before and after the analysis) between the experimental group and the control group that gives meaning to the experiment. Another well-known example of scientists agreeing upon a certain ground rule to try to minimize subjectivity in their experimental results is the use of $P < 0.05$ to determine statistically significant results (in most cases). Yet, no ground rule has (or can) regulated scientists' own personal perception of their results (Berman, 1981/1989; Cleminson, 1990). The inherent ability of the human mind to create its own perceptions and contexts prevents that. That is why repeatability and peer review are such important characteristics of scientific research, so that many perceptions of what may have happened in an experiment may be considered.

In radical constructivism, the instructor assumes the role of guide or coach, assisting students to develop their own individual learning strategies, acknowledging that there will be a great deal of diversity in learning styles for any group of students. Learning activities that are ideal for this philosophy include PBL (Duffy and Bednar, 1991), cognitive apprenticeship (Bednar *et al.*, 1992), and activities that specifically stimulate the development of student metacognition (Honebein *et al.*, 1993). Because of the importance of both student diversity and student metacognition in developing individual realities, it is vital in radical constructivism for students to see and solve problems or perform tasks from alternate perspectives. Thus, Schön (1987) says that the learning process has "at least as much to do with finding the problem as with solving the problem found" (p. 18). This "problem setting" stimulates students to think critically and strategically to solve problems in a world where there are many and diverse contexts (Jones *et al.*, 1995).

3) Situated constructivism. Situated constructivism, derived from a theory originally referred to in the literature as the "sociology of knowledge" (Mannheim, 1929/1936), is much like radical constructivism in that it assumes there is no objective reality, but rather than focusing on personal perceptions as radical constructivists do, situated constructivists believe that interpretations of events in the environment and the context of those events are based on the social patterns that we observe and practice over time (Resnick, 1987; Brown *et al.*, 1989; Jonassen, 1991). Because we are members of a society, and because all members of that society have their own personal perceptions and realities, situated constructivists hold that we are members of a *multi-universe* (Young 1997; Kanuka and Anderson, 1999). According to this view, while we can only personally perceive one reality, we are members of many realities (see comparisons with other forms of constructivism in Table 1).

While situated constructivism seems superficially to have similar implications to cognitive constructivism in that students actively struggle with a variety of opposing understandings (Cunningham, 1991; Spiro *et al.*, 1991), situated constructivism in fact invites learners "to 'bracket' their intuitive models for a while and just learn a new way of thinking and talking about the phenomena. When the new way has become somewhat familiar and consolidated, then the instruction turns back to the naïve model and explores relationships between the two" (Perkins, 1991, pp. 19-20). The ideal type of learning activity using a situated constructivist philosophy is a PBL activity that gives students as opportunity to develop "advanced knowledge acquisition in ill-structured domains" (Molenda, 1991). This advanced knowledge acquisition (including metacognition) gives students a learning flexibility which can be used "to find the most useful of the valid representations to fit the needs of a particular case. [This requires the availability of] a diverse repertoire of ways of constructing situation-sensitive understandings" (Spiro *et al.*, 1991, p. 22). The ultimate goal of instruction is to help the learner understand multiple perceptions of reality, rather than to teach "The Truth" (Kanuka and Anderson, 1999; Styer, 2002).

4) Co-constructivism. According to co-constructivism, also known as social constructivism, knowledge is built socially through the use of language (Vygotsky, 1934/1962; reviewed in Prain and Hand, 1996a). Co-constructivists hold that knowledge is constructed though cultural collaborative use of language implicitly limited to the context of the environment (Vygotsky, 1930/1978; Baxter Magolda, 1992). Jonassen (1991) says, "the mind is instrumental and essential in interpreting events, objects, and perspectives on the real world, and that those interpretations comprise a knowledge base that is personal and individualistic" (p. 29). While situated constructivism believes in multiple realities based on perceptions of the universe that are impossible to share, co-constructivists hold that knowledge and understanding can be shared by agreed-upon socio-linguistic meanings. In other words, knowledge of reality is created through conversation upon the meanings of what two individuals are discussing, and if this conversation results in agreement, the agreement is reality (Kuhn, 1962; Vygotsky, 1930/1978; Kanuka and Anderson, 1999). Halliday and Martin (1993) claim that the language of scientific discourse is "actively engaged in bringing such structures into being" (p. 8) and define a scientific theory as "a linguistic construal of experience" (p. 8). For example, chordates and echinoderms (starfish, urchins, *etc.*) appear to have next-to-nothing in common, and if we based our knowledge of evolution entirely on macroscopic morphology in adult organisms, we might not realize the two phyla are actually closely related. But because scientists have defined developmental biology as an important part of determining cladistic relatedness, the reality is that echinoderms and chordates are both deuterostomes (the anus end of the digestive system forms before the mouth end) and thus closely-related.

To use another example, everybody agrees that there is an object in the outer solar system named Pluto. Nobody doubts its existence. But what is it? A planet or a Kuiper Belt Object? That debate is one of the more contentious disputes in astronomy (Andersen, 1999). It is likely to become even more contentious with the discovery of a Kuiper Belt Object (2003UB313) that is even bigger than Pluto (Kerr, 2005). For some, reality is a solar system of 8 planets, ending with Neptune. For others, reality is a solar system of 9 planets. And for others, reality is a solar system with 10 planets, including 2003UB313. Cognition is a matter of perception, definition, and language. For example, what is the definition of a species? Two organisms are defined as belonging to different species when they are incapable of breeding and producing fertile offspring, except in the case of dogs and wolves, which do produce fertile offspring when bred, and yet are considered different species. What is the scientific rationale for classifying dogs and wolves as different species? There is none. There is only tradition, and more than anything, tradition is defined by language. Does light consist of waves or particles? The answer to that question depends on what the particular phenomenon being studied is, and whether it can be understood by perceiving light as consisting of waves or particles.

Co-constructivism is the most prevalent of constructivist epistemologies (Kanuka and Anderson, 1998). Social negotiation often takes the form of argumentation and Socratic dialogue, similar to what happens in cognitive constructivism. The emphasis of co-constructivism, however, is on constructing knowledge that is dependent upon its context and upon the semantics that the group has agreed to use. Primary forms of instructive methodology include small discussion groups, brainstorming and categorizing, debriefing, and testing of ideas against alternative views and alternative contexts (which is also a good way of assessing transferability of knowledge; Gick and Holyoak, 1983). Communication between students is vital to co-constructivist philosophy. Modern electronic distance education provides a new and unique environment that provides "an effective means for implementing constructivist strategies that would be difficult to achieve in other media" (Driscoll, 1994, p. 376; also see Nicaise, 1998).

Impact of Constructivism on Science and PBL Pedagogy

Prain and Hand (1996a) sum up the constructivist view of science and its implications on education in general in this way:

> The debate [between different constructivist views] indicates there is broad theoretical consensus that it is impossible to obtain "true knowledge about reality from our experiences and experiments" (Solomon, 1994, p. 14), from inductive logic, and that scientific epistemology now rests predominantly on social and consensual grounds...However, in practice all perspectives adopt what Woolgar (1993, p. 183) has shrewdly labeled "ontological gerrymandering". By this he means that a tacit or overt case is made for different forms of empiricism (different degrees of closeness to, or distance from, "reality") as being more valid than others, as though this meta-narrative of how to experience the world can be rendered divisible for the sake of procedural convenience, or to overcome the logical impasse implicit in the sociological perspective. This is the "as if" position. Scientific learning will proceed "as if" induction might provide some provisional "truths" as the basis for the construction of scientific knowledge. This is evident at the conceptual level of the debate in the current consensus about "what is learning science".

> There is agreement that learning science must be more than the mere rehearsal of students' prior or alternative conceptions of life-world knowledge, tested or untested against their experiences. Scientific knowledge...is not the exact equivalent of the life-world understanding of learners, how much these constructions may be said to intersect, overlap, parallel, or echo one another. At the pedagogical level there is also agreement, despite some rhetorical flourishes in the name of apparent differences, that students' prior understandings are a crucial focus for effective learning of new knowledge. As Martin (1993, p. 170)...has noted, "common sense knowledge can be a very useful starting point for learning science, since it organizes the world in ways that can be clearly related to scientific understandings".

Savery and Duffy (1995) identify three general constructivist principles that are important to PBL: understanding comes from our interactions with the environment, cognitive conflict stimulates learning, and knowledge evolves through social discourse and evaluation of the viability of individual understandings. All these principles are constructivist in nature and are explicitly fulfilled through PBL. PBL instructors, as a result, become facilitators, coaches, and mentors, rather than the positivist stereotypical "fount of knowledge" (Collins *et al.*, 1989; M. G. Moore, 1993; Mullins, 1994; Russell *et al.*, 1994).

An important aspect of constructivist PBL is student role-playing. Renner (1997) characterizes role-playing as experiential learning at its best and can be used to "insert a slice of life into the classroom, connect theory with everyday practice, practice unfamiliar skills in a safe setting, and learn to appreciate contradictory viewpoints" (p. 64). Role-playing can be made even more interesting by allowing students to have an "alias". Using an alias system, the instructor can assign roles to students, and even require them to role-play an individual of a different gender, socioeconomic status, ethnic origin, or age. The students must then not only act from an alternate perspective, but also respond to classmates who will not know the true identity of that individual. This type of system can help students develop an appreciation that much of what we know to be "true" may be contextually and culturally situated (Kanuka and Anderson, 1999; Styer, 2002).

Obviously, the instructor must devote much planning to create an effective PBL situation. The following are important factors to keep in mind when creating constructivist-based PBL situations (Lacey and Merseth, 1993; Mierson, 1998; Kanuka and Anderson, 1999):

- Selection of learning objectives, both material-specific and interpersonal/social.
- Providing background: What is the problem? This includes the nature of the environment that the problem exists in, the stakeholders, the resources available, and any time frames that apply.
- Relevant information that has a major influence on the stakeholders in terms of specific events, facts, and circumstances, including social contexts and previous experiences.
- Discussion questions to help guide the learners in their exploration of these issues. The questions may lead students to consider alternative solutions, recognize contributing influences, and anticipate possible consequences.
- Important facts and incidents should be easily recognizable.
- Stakeholders should be clearly identified and pictured as to who they really are, not just superficially. They should be linked clearly to the problem.
- Brief dialogues can give students a sense of who the stakeholders involved truly are in a deep sense.
- Include social/organizational content.

The concluding sentence of a PBL problem should point out a need for some form of action. On-line students also require some form of discussion forum in which to communicate asynchronously but privately, and where their discussions can be recorded for possible analysis (Kanuka and Anderson, 1998). In such a discussion forum, students can constructively negotiate their understanding through a socio-linguistic process yielding the development of new solutions, the inspiration of collective creativity, and the effecting of group synergy (Renner, 1997; Hand *et al.*, 1999; Klemm, 2002). The importance of synchronous communication (such as on-line chats) is debatable. In the future, universal high bandwidth may make videoconferencing a viable means for student communication (perhaps eventually a vital means but perhaps not). Currently, however, videoconferencing is practical only at places with dependably high bandwidth such as colleges, which eliminates the whole *raison d'être* of on-line classes.

Pedagogical Concerns in PBL at the Dawn of the 21st Century

Cooperative Learning

PBL is typically conducted using cooperative learning groups (Anderson and Henley, 1994; White, 1996). Cooperative learning is a "learner-centered instructional process in which small, intentionally selected groups of 3–5 students work interdependently on a well-defined learning task; individual students are held accountable for their own performance and the instructor serves as a facilitator in the group learning process" (Cuseo, 1992). This role of the instructor as "facilitator" rather than "fount of knowledge" makes cooperative learning a powerful educational tool in constructivist learning philosophy. The emphasis on students learning together as a group and creating their own learning through discussion, negotiation, and perhaps some Socratic *elenchus* as well, is clearly co-constructivist in nature (Vygotsky, 1930/1978; Cuseo, 1992). In addition, students practice working in collaboration, a skill that is increasingly in demand in the modern world. The importance of social skills needed for collaborative work are recognized by the popular culture's embrace of the psychological idea of "emotional intelligence," which includes such skills as empathy, the ability to use emotions to facilitate other cognitive activities, and managing emotions in a productive manner (Grewal and Salovey, 2005). Ideally, cooperative student learning groups should be as heterogeneous as possible to maximize the breadth of experiences, social, and academic skills available to the group (Tinzmann *et al.*, 1990; Cuseo, 1996). Nevertheless, the PBL paradigm can provide sufficient scope for individual study disciplines to be developed (Navarra *et al.*, 1993; however, the opposite viewpoint is implied by Tolnai, 1991).

PBL and Electronic Distance Education

PBL is usually conducted in a face-to-face setting, especially in the medical and social sciences, and in pre-professional and professional programs (reviewed in Michel *et al.*, 2002). Little is known about the use of PBL in the electronic-based distance-education "virtual classroom." Klemm (2002) found that cooperative learning case study groups thrive in the electronic environment; however, Klemm's "case studies" were actually reviews of journal articles, and computer conferencing was used as an adjunct to face-to-face meetings between students in a traditional class. The Internet, however, allows a different kind of class experience that doesn't require students to ever meet each other in person. The versatility of the Internet, combined with its cost-effectiveness in overcoming the geographic limitations of the traditional university, presents educators with an unrealized potential to produce pedagogically- and scientifically-sound authentic learning experiences, including PBL, that allow for multidisciplinary projects, cooperative learning groups, flexible scheduling, and authentic assessments in distance education courses. They may revolutionize, supplement, complement, and enrich science education, both at a distance and in the traditional college setting (Oliver and Harrington, 2000).

History of Distance Education Technology

Early History

Distance education in the United States is most broadly defined as "an educational process in which a significant proportion of the teaching is conducted by someone removed in space and/or time from the learner" (Perraton, 1988, p. 34). Distance education was born in 1833 in the form of correspondence classes, first in Sweden, then across Europe, and finally the United States (Holmberg, 1986). In 1883, the first correspondence course in the United States was established by the State of New York in the form of the Chautauqua Institute, which trained Sunday school teachers (Watkins, 1991; Clark, 1999c). Illinois Wesleyan University offered bachelor's, master's, and doctoral degrees via correspondence through a program that had a peak enrollment in 1900 of nearly 500 students. However, the program was terminated in 1906 due to concerns about educational quality (Holmberg, 1986).

At the University of Wisconsin, the foundation for university extension was laid in 1885 with the establishment of "short courses" and farmers' institutes. Correspondence study at Wisconsin began in 1891, was discontinued in 1899, and re-established in 1906 when the University of Wisconsin's Extension Division was re-organized (Watkins, 1991). Pennsylvania State College established an extensive correspondence program in agriculture in 1892 based specifically on the Chautauqua approach (Borsari, 1998). Other educational institutions that were instrumental in the development of correspondence courses included the University of Chicago, University of Nebraska, Ministry of Education (France), Skerry's College (Scotland), University Correspondence College (England), International Correspondence Schools (Pennsylvania), Society to Encourage Studies at Home

(Massachusetts), Sir Isaac Pitman Correspondence College (England), Hermod's (Sweden), and the secondary school district of Benton Harbor, Michigan (reviewed in Hanson, 1997).

Electronic Revolution

Distance education has always been an area of a great deal of innovation due to the development of new technology and new paradigms that improve learning at a distance. The development of wireless communication allowed for rapid bursts of growth in distance education, followed by equally rapid periods of disillusionment and contraction. This pattern was established with the advent of radio in the 1920s, when 176 radio stations were established at educational institutions. Many of these stations were terminated following the stock market crash in 1929. Most of the surviving stations were at land grant colleges (Hanson, 1997).

Experimental television teaching programs were produced in the 1930s at the University of Iowa, Purdue University, and Kansas State College. The first robust set of college credit courses was offered by Western Reserve University in 1951. New York University produced "Sunrise Semester", a series of televised college courses that appeared on CBS from 1957 to 1982, usually at 5 a.m. (and that was before the invention of the VCR!) (Hanson, 1997). In 1971, the U.K. made a significant investment in telecourses with the establishment of the Open University in Milton Keynes, Buckinghamshire (Open University, 2005). Lack of interactivity was a major shortcoming with telecourses, however (Chu and Schramm, 1967). Today, the only nation that is investing heavily in telecourses is China, with 45 Radio and TV Universities, 841 branch schools, and 1,768 work stations as of 2000 (Ding, 1994, 1995; China Education Research Network, 2000). However, Dunn (2000) reports that some American companies are beginning to publish television-based courseware to support the growing home schooling movement.

Satellite-based telecourse technology was developed during the U.S.-Soviet space race of the 1960s, experimented with in the 1970s, and made cost-effective in the 1980s. Pioneering efforts with satellite telecourses included the Appalachian Education Satellite Project, Learn/Alaska, and the TI-IN Network of San Antonio (Albright, 1988; Johnson, 1988; Hanson, 1997). A similar but brief flurry of excitement accompanied the development of fiber optic communication systems in the 1980s, as illustrated by the $500 million Iowa Communications Network (Simonson, 1997).

The mid-20th Century also marked the birth of the computer as a powerful educational tool to assist instruction. Even as early as the 1960s, research indicated that students learning with computer-assisted drill-and-practice exhibited similar performance on the Stanford Achievement Test to students in a control group (Suppes and Morningstar, 1969). From its very beginning, the promise of computer-assisted instruction was recognized, especially in areas where education was substandard, because of a lack of opportunity, a lack of qualified teachers (Suppes and Morningstar, 1969), or a lack of demand (Pridmore, 1999).

Birth of the Internet

The Advanced Research Projects Agency Network (ARPANET) was an effort by the Department of Defense to decentralize America's military computer network in case of a nuclear attack by the Soviet Union. Conceived as part of the United States' response to the launch of the Soviet *Sputnik* satellite (Hauben, 1994), and established in 1969, ARPANET became the birthplace of a number of smaller networks and networking technology, including the use of TCP/IP (1977), Telnet (1983), and FTP (1985), and the development of

UseNet (1979), MILNET (1984), and NSFNet (1986) (Wikipedia, 2005). With the conclusion of the Cold War in the late 1980s, the Department of Defense began to shut down ARPANET (the last node was deactivated in 1989), turning over management of the nascent Internet to the National Science Foundation (NSF). In 1995, NSF privatized access to the Internet, and, combined with the introduction of the HTML language and HTTP protocol by Tim Berners-Lee in 1989, the explosive growth of the Internet began (Wikipedia, 2005). Due to the power of decentralization, the Internet has become the obvious medium-of-choice for distance educators around the world (Berge, 1997; Pridmore, 1999; Dunn, 2000).

Many distance teaching universities have moved much of their operation onto the Internet. These include the Open University (U.K.), Fern Universität (Germany); Athabasca University (Canada), the University of South Africa, Technikon SA and Vista University (both also in South Africa), University of Twente (Netherlands), the Open University of Israel, Universidad Nacional de Educación a Distancia (Spain), the Open University of the Netherlands, the Open University of Sri Lanka, and many others (reviewed in Hanson, 1997). In the United States, most American universities are moving some classes onto the Internet, and are sharing their experiences with Internet education in an effort to improve Internet education across the board. These efforts have produced collaborative organizations such as the Asynchronous Learning Network, Illinois' Sloan Center for Asynchronous Learning Environments, and Colorado's Association for Managing and Using Information Resources in Higher Education. Indeed, Dunn (2000) predicts that by 2025, virtual courses will be the predominant mode of higher education. Unfortunately, with the increasing profile of Internet-based distance courses will also come increasing problems with fraudulent Internet-based diploma mills, making the maintenance of high quality in legitimate on-line classes by legitimate universities that much more important (Lord, 1998).

Distance Education Pedagogy

Generations of Distance Education Design

The process of "getting courses moved on-line" in higher education has to date focused on technical expediency and ease of transition of a face-to-face class to Internet-based delivery (Oliver and Harrington, 2000; Maddux, 2002; Stevens, 2002). The use of traditional assessment tools and the treatment of the subject material as a static entity that can be "downloaded" to students as if they were computers draws attention away from pedagogical research into student-centered learning environments and limits instructors' creativity in designing educational innovation (Jonassen, 2000; Maddux, 2002).

Pedagogically, historians of distance learning often divide the evolution of distance education into a number of "generations" based on the technological tools that support each generation and the pedagogical philosophies that can be utilized using this technology. However, it is possible to use advanced technologies to deliver older generation pedagogies, so there is not an automatic correlation between advancing technologies and advancing pedagogies (Garrison, 1985; Nipper, 1989).

The first generation of distance education design is characterized by an industrial or Fordist model based on economy of scale (Peters, 1988; Campion and Renner, 1992; Dunn, 2000). This generation can be symbolized by the traditional printed textbook and accompanying course guide, designed by experts (instructional designers, graphic artists, editors, project managers, *etc.*) to reflect a conversation between an absent teacher and the independent student (Garrison and Anderson, 2003). First generation pedagogy is based on the stimulus-response system central to behaviorism, which was the philosophy that allowed researchers to empirically conduct experiments on the psychology of a subject (Watson, 1913). The instructor's task is to develop "the arrangement of contingencies of reinforcement under which students learn" (Skinner, 1968, p. 64). Students are characterized by "independent study"; they are free from a timeline and speed dictated by an educational institution. Correspondence courses and many Internet-based courses are first generation. First generation assessment is based on exams. The design of first generation courses precludes cooperative learning and does not take advantage of the Internet's hyperlinking capability and vast array of information and knowledge resources available for exploration (Garrison and Anderson, 2003).

The second generation of distance education design evolved in the mid-20th Century, an era characterized by the post-World War II revolution in psychology and the rise of popular media, with its emphasis on aesthetically flashy audiovisual presentation (and short attention spans). Expensive media productions were created that allowed students to virtually visit the laboratory, workplace, or stay within the classroom with audio and/or video images of the instructor. As Garrison and Anderson (2003) point out, "advances in cognitive learning theory led to the use of advanced organizers, role models, summary reflections and simulated peers to draw the user into a sophisticated media world" (p. 37). Second generation technology in theory was to allow more interaction between students and delivery institutions. However, the skyrocketing front-end cost of production led to a situation where the "teacher" was actually a course tutor whose job was to support and assess student achievement (Bates, 1995). More recent manifestations of second generation design include interactive CD-ROM or DVD courseware, and simulations, multimedia drill and practice, and self-paced tutorials that can be downloaded and execute on the student's computer (as opposed to a central server) (Garrison and Anderson, 2003). However, perhaps the ultimate pinnacle of second generation design is in the area of informal "edutainment" that does not involve local teachers or tutors, assessment of any kind, or institutionalization of education in any form. This "edutainment" is symbolized by educational TV networks such as PBS, the Discovery Channel, Animal Planet, and the History Channel.

The third generation is characterized by highly integrated content, assignments, and projects combined with copious amounts of communication, both synchronous and asynchronous, via computer technology (Garrison, 1985; Nipper, 1989). Third generation design embraces "constructivist learning theories to create opportunities for students to create and re-create knowledge, both as individuals and as members of learning groups. This knowledge construction takes place within the negotiation of content, assignments, and projects and is elaborated on in discussion, collaborative projects, and resource- or problem-based curriculum designs" (Garrison and Anderson, 2003, pp. 37-38).

Taylor (1995, 2001), however, has articulated fourth and fifth generations. Taylor's fourth generation is characterized by high amounts of content retrieval, full utilization of the interactive capacity of computer-mediated communication, and use of locally distributed processing (possible due to the rise of the Java programming language) (Lauzon and Moore, 1989; Taylor, 1995). Taylor refers to the fifth generation as the "intelligent, flexible learning model." This model features the integration of portals to resources, artificial intelligence to exploit the "semantic web", and "intelligent agents" that are long-lived, semi-autonomous, proactive, and adaptive, capable of monitoring resources and making decisions (Taylor, 2001). The fifth generation promises to build semantic meaning into the Internet, such that it can be navigated and processed by both humans and artificially intelligent non-human "autonomous agents" (Berners-Lee *et al.*, 2001). Virtual reality or haptic interfaces may also provide environments where learning can occur in a highly realistic setting (Young, 1999; Gardner, 2000).

While educational philosophers argue whether or not these fourth and fifth generations are actually just continued evolution of the third generation, what these technological developments illustrate is the flexibility and largely unrecognized potential of the Internet. As Mitchel Resnick observed (1996):

> The Internet acts as a type of Rorschach test for educational philosophy. When some people look at the Internet, they see it as a new way to deliver instruction. When other people look at it, they see a huge database for students to explore. When I look at the Internet, I see a new medium for construction, a new opportunity for students to discuss, share, and collaborate on constructions.

Interaction

The most revolutionary aspect of the rise of the Internet when compared to older forms of distance education delivery is the transformation of interaction that the Internet allows. Dewey (1938) defines an educational experience as an interaction taking place between an individual and his or her environment. Garrison and Shale (1990) define all forms of education as interactions among teachers, students, and content. Or, in other words, the "keys to the learning process are the interactions among students themselves, the interactions between faculty and students, and the collaboration in learning that results from these interactions" (Palloff and Pratt, 1999, p. 5). Laurillard (2000) argues that a university education must include "engagement with others in the gradual development of their personal understanding" (p. 137).

The rise of the Internet supports a number of functions that affect interaction between students, between students and instructors, between students and content, and between instructors and content (M. G. Moore, 1993; Berge, 1997; Hedges and Mania-Farnell, 1998; Lou, 2004). The functions that have the greatest implications upon student learning are:

1) Pacing. In collaborative learning, interactive pacing keeps a group synchronized and acting together. In individual learning, interaction (between the instructor and student) defines a speed so that educational objectives are completed in a reasonable and pedagogically effective period of time. Keeping a balance between those two aspects of pacing is a tricky part of instructional design (Hannafin, 1989).

2) Elaboration. Interaction allows learners to construct connections between new and existing information and skills (Hannafin, 1989).

3) Confirmation. The most behavioralist function of interaction includes not only assessment interaction with the instructor but also interaction with peers in cooperative learning and PBL (Hannafin, 1989; Hedges and Mania-Farnell, 1998).

4) Navigation. Guides the way that learners interact with content (Hannafin, 1989).

5) Inquiry. Governs student interaction with the immense research resources of the Internet (Hannafin, 1984).

6) Study pleasure and motivation. *Homo sapiens* is a social animal, even in learning (Holmberg, 1989). Socialization of study can also induce "awareness," the critical attention to detail and involvement (Langer, 1997). Due to its desirability, pleasure stimulates neurons to release CREB, which strengthen neural synapses, strengthening memories of the pleasurable event (Fields, 2005). Presumably that memory would include the subject material covered during the social study session.

However, the social construction of knowledge via interaction in an on-line environment can be hindered by many factors, including unconscious incomprehension of constructivist philosophy and its role in science (for instance, not recognizing one's own subjectivity of thought processes, or intolerance of competing theories or hypotheses) (Ryan and Aikenhead, 1992; Carey and Smith, 1993; Hand *et al.*, 1999), a lack of emotional intelligence or social charisma (or, to use the slang, "personal chemistry") between group members (Stukus and Lennox, 1995; Wright *et al.*, 1998), and technophobia. Despite the modern ubiquity of computer-mediated communication, a significant number of students, including science majors and computer-literate students, are technophobic (Guttschow, 1999; Anthony *et al.*, 2000; Todman, 2000). The onus is on the instructor in the on-line environment to facilitate communication and aid successful research on the Internet by providing encouragement to develop computer skills through regular repetition (Hedges and Mania-Farnell, 1998), explicit instructions (Cruickshank and Olander, 2002), a secure environment in which students can learn (without forcing them to resort to external searches that may lead them to undesirable sites such as those promoting pseudoscience and pornography), and a support system for students with technical problems, including the service of a technical specialist and instructor time for synchronous communication (Napholz and McCanse, 1994; Jensen *et al.*, 2002).

The Future of Distance Education

The Internet continues to have a tremendous impact on the institutions of the 21st Century, including educational institutions. Garrison and Anderson (2003) predict:

> Like bandwidth, content *per se* will have little direct value in the near future. If the trend continues, as it surely will, there will be virtually unlimited bandwidth and unlimited content storage at very little cost and, consequently, access to infinite content. The smart position for an educational institution is where many prestigious universities are positioning themselves now by adding value to the context or interactive side of the educational equation, creating quality-learning experiences that are engaging, relevant, and responsive...The discourse is shifting from the "e," or technology component, to the real issue – learning. That is, a quality-learning experience, regardless of communication mode or medium.
>
> Educators can no longer sit on the sidelines without becoming irrelevant, without becoming extinct. Expectations are changing too rapidly...There are infinite possibilities and no single right way. Educators must assess their students' needs and find where and how they need to add value. More of the same, or doing the same thing more efficiently, misses the point. We do know that the role of educators is no longer simply presenting or providing access to content. Content is ubiquitous. The value-add of e-learning is creating a unique community of inquiry. It is in the design of an integrated social, cognitive, and teaching environment.
>
> (Garrison and Anderson, 2003, pp. 116-117)

> The challenge for 21st Century educators is to create a purposeful community of inquiry that integrates social, cognitive, and teaching presence in a way that will take full advantage of the unique properties of e-learning; those interactive properties that take learning well beyond the lecture hall and information assimilation. These properties of e-learning are capable of creating a community of inquiry that is independent of time and space and with the combination of interactive and reflective characteristics that can stimulate and facilitate a level of higher-order learning unimaginable to date.
>
> (Garrison and Anderson, 2003, p. 123)

Or, as Marshall McLuhan famously stated, "We shape our tools, and thereafter our tools shape us" (McLuhan, 1964/1994, p. ix). How will the continued development of the electronically capability of the Internet transform education in the 21st Century? That will be determined less by the Internet, and more by the educational community itself (Gardner, 2000).

Potential of Distance Education Technology to Revolutionize PBL

Students often miss important ideas in their classes because their knowledge is not oriented towards recognition of meaningful patterns and not as flexible as that of experts (deGroot, 1965). The introduction of a PBL environment that immerses students in a particular situation provides a context in which initially abstract concepts are transformed into a more nuanced form of understanding (Engeström, 1999). The net result is that students are forced to construct an understanding that combines elements of both pre-existing relevant knowledge and new information learned in class. In working through the problem presented by the PBL situation, a student's understanding develops into the meaningful patterns and principles that govern the topic (National Research Council, 2000). In short, students begin to develop "adaptive expertise." Adaptive expertise is a form of flexible, opportunistic, exploratory, and creative thinking that distinguishes "highly competent" from "merely skilled" practitioners, or more colorfully, "virtuosos" from "artisans" (Miller, 1978; Hatano and Inagaki, 1986).

In an immersive environment, students deal with the exigencies at hand. Thrust into an unfamiliar role, they quickly recognize what they don't understand, the necessary first step of learning (Checkley, 1995; Bransford and Schwartz, 1998). This recognition process may be intellectually uncomfortable for students, but it forces them to draw on their previous experiences both from classes and from extracurricular experiences as they struggle to make sense of a new situation. The deficiencies in the student's understanding needed to come to a conclusion are apparent and ready to be filled by the expertise of the instructor or other experts whose understanding can be tapped. For example, many students go through introductory biology courses that introduce the molecular and physiological mechanisms of genetic diseases such as sickle-cell anemia, cystic fibrosis, and Huntington disease. However, it is one thing to know facts about these diseases in the abstract, but quite another thing to role-play a genetic counselor, family member, employer, or insurer dealing with an individual with a family history of one of these diseases. In the latter case, the necessary understanding of the molecular and physiological properties of the disease are joined by an equally necessary attention to legal concerns, ethical and professional practices, social and interpersonal discourses, and even a philosophical introspection on the nature of death (or at least disability). The context of the problem simply provides a foundation upon which the student can perceive, interpret, and judge the relevant issues (Broudy, 1976; Nicaise, 1998). This perception, interpretation, and judging involves the critical attention to detail and involvement that is such an important determiner of learning (Langer, 1997).

The decentralized networking power of the Internet makes possible a very rich immersive PBL environment. Instead of just reading about an individual with a problem that the students must make a decision about, students can watch him in an interview, at work, and at home, leaf through his personal papers (if he is fictional), and even talk to an actor playing the part of the individual. Instead of just reading about the technology that could be used to help make a decision and reading abstract philosophical theories about ethical matters involved in such a decision, students can role-play the role of experts themselves, and also listen to and communicate with real-life experts both inside and outside the university. Students can learn how to transfer their learning to other case studies involving superficially-similar but quite different situations, which causes their learning to be modified into more abstract general principles instead of rigorous methodology on how to solve such a problem only in the original context (Gick and Holyoak, 1983; Collins *et al.*, 1989; Salomon *et al.*, 1991). By becoming emotionally involved in and internalizing the problem, students develop an understanding that allows them to translate scientific information from a highly technical language to a layperson's language, another form of knowledge transfer that demonstrates higher-order learning (Sutton, 1993; Wright *et al.*, 1998). Often, this translation involves transfer from previous experiences, as metaphors and similes help illustrate complex ideas and give students an opportunity to express their creativity in prose (Ambron, 1987; Sutton, 1992; however, for the opposite viewpoint, see White and Welford, 1987; Martin, 1993; Carr *et al.*, 1994). The Internet provides a particularly suitable environment, as students with right-brain dominance (visually-oriented students) on average perform better in on-line courses than students with left-brain dominance (auditory-oriented), who score better on average in lecture classes (Benedict and Coffield, 1989). Having students express their knowledge in their own words also reveals fundamental flaws and misconceptions in a student's constructed understanding which the instructor can then focus on remedying (National Research Council, 2000; Nazario *et al.*, 2002).

Finally, an immersive PBL environment can help students develop metacognition. Metacognition, which is often defined as "learning how to learn", is the ability to monitor one's own learning of material. Metacognition is a defining characteristic of adaptive expertise and helps to generate an ability to transfer learning from one situation to another by focusing on critical elements, abstraction of common themes or principles, and evaluation of one's own progress toward understanding (Bielaczyc *et al.*, 1995; White and Frederickson, 1998; National Research Council, 2000). According to Wright *et al.* (1998), "curriculum reform is most effective in changing student habits of the mind." Emphasis on helping students develop metacognition of the importance of abstraction is one learning aspect that is vital to navigating one of the pitfalls of PBL: the over-contextualization of information (Barrows, 1985; Williams, 1992; Hmelo, 1995). Teaching students how to learn is also an important part of generating life-long learning (Checkley, 1995; Erlendsson, 2001). As Bransford and Schwartz (1998) say:

> Here the focus shifts to assessments of people's abilities to learn in knowledge-rich environments. When organizations hire new employees, they do not expect them to have learned everything they need for successful adaptation. They want people who can learn, and they expect them to make use of resources (*e.g.* texts, computer programs, colleagues) to facilitate this learning. The better prepared they are for future learning, the greater the transfer (in terms of speed and/or quality of new learning).
>
> (p. 68)

CHAPTER 3

DESIGN OF THE PROBLEM-BASED LEARNING UNIT

The Course

A PBL unit has been used in several versions in an entirely on-line course entitled "Biotechnology in Agriculture, Food and Human Health" (GEN 308/508), offered through the Department of Genetics, Development and Cell Biology at Iowa State University. The course is part of a program called Project BIO. Project BIO (http://project.bio.iastate.edu) is a partnership for biology education to develop and share biology education resources via the Internet. The partnership involves faculty, staff, and students at Iowa State University, Iowa community colleges, Iowa high schools, and select Iowa industries. Among the several activities of Project BIO are Internet-based distance education classes, including Principles of Biology (introductory majors course), Introductory Biology (non-majors course), Introduction to the Human Body (non-majors), Environmental Biology (non-majors), Principles of Microeconomics, and Principles of Macroeconomics. One of these courses is Biotechnology in Agriculture, Food and Human Health.

The biotechnology course is a three-credit survey course that covers technology and applications of biotechnology as well as ethical, legal and social issues (ELSI) associated with its use. It can be taken for credit towards a major in one of the biological sciences, though many non-majors take the class as well. The course can be taken for undergraduate credit (GEN 308) or graduate credit (GEN 508). The difference between the two courses consists of a creative component at the end of the semester. When first conceived, the principal student market for the class was considered to be educators. However, since then, the bulk of the students have been a mix of traditional undergraduate and graduate students majoring in molecular biology or genetics or working in an on-campus lab, professionals working for seed or other biotechnology companies (often these students have a business rather than a science background), and farmers who want to learn more about the seeds they are planting and harvesting. There have been other students from all walks of life, including military personnel, lawyers, engineers, and an assistant state secretary of agriculture. Students are geographically diverse, with nearly every Iowa county and U.S. state represented, as well as students logging in from Canada, Germany, and Kenya. The course is offered three times per year, and the number of students typically ranges from 15–30 students per semester, with a typical 25–30% drop rate between the beginning and end of the semester.

In the late 1990s, the course was hosted on its own architecture through a Project BIO server and used the now-defunct ISU ClassNet system for communication and managing assessments. Beginning in Summer 2001, the course switched to the WebCT architecture utilized by many on-line classes at ISU (Figure 1). The course consists of on-line audiovisual lectures that are modeled after lectures in a face-to-face classroom (utilizing on-line slides accompanied by a streaming audio/visual lecture; see Figure 2), authentic learning assignments (Figure 3), and reading assignments in a required textbook (Alcamo, 2001) and from various on-line resources (databases, articles, tutorials, *etc.*). Approximately 60% of the grade in the course is based on authentic learning activities and the other 40% is from on-line exams based on content in the on-line lectures and reading material. Exams are password-protected and require the presence of an approved proctor (such as a county extension agent outside Story County or an employee of the Center for On-Line Learning at ISU for students within Story County) to prevent student cheating. Within the WebCT architecture, students can communicate with the instructor and with each other through an in-class e-mail system, a bulletin-board-style discussion forum with both public and private boards (Figure 4), and both public and private chat rooms.

The biotechnology course is designed using a modular system. All students complete the first 3 modules of the class. Undergraduate students then complete either Module 4 or Module 5, depending on their professional or personal interests in agriculture or medical

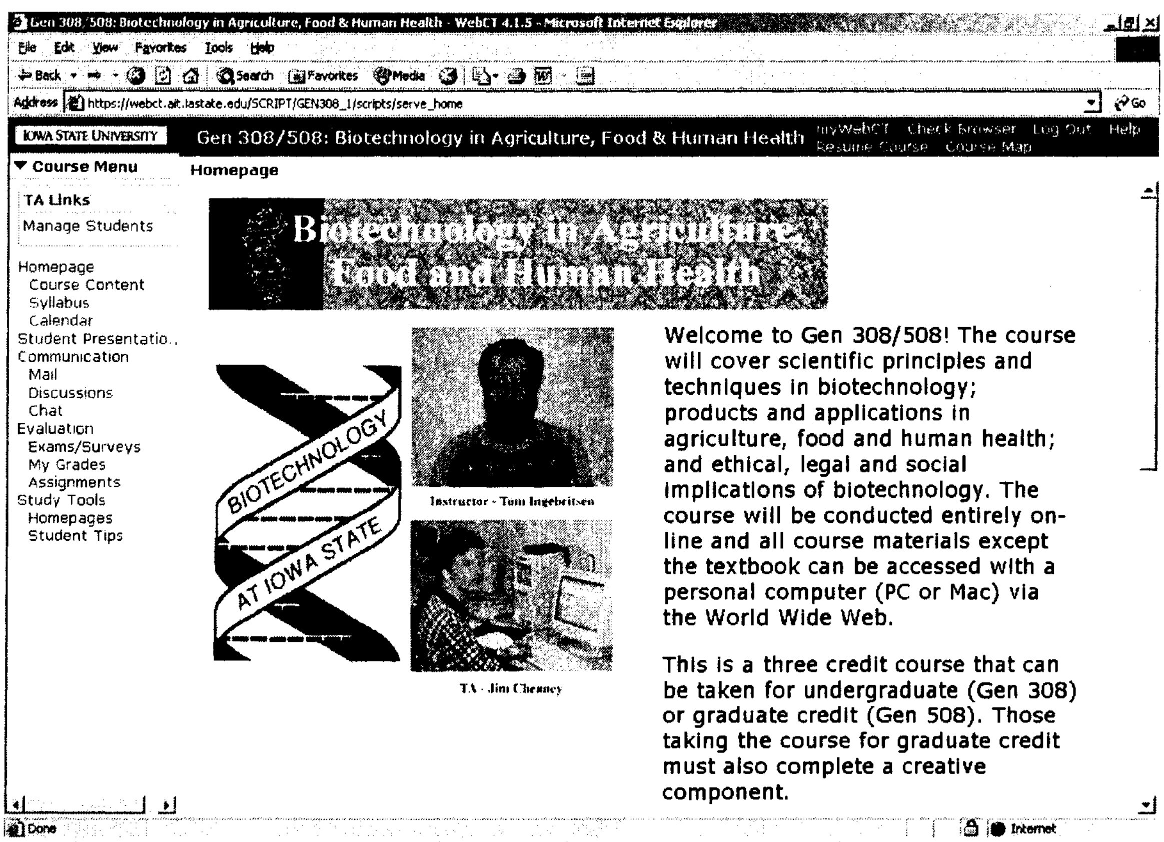

FIGURE 1. Homepage for Biotechnology in Agriculture, Food and Human Health. The class utilizes the WebCT architecture licensed to Iowa State University.

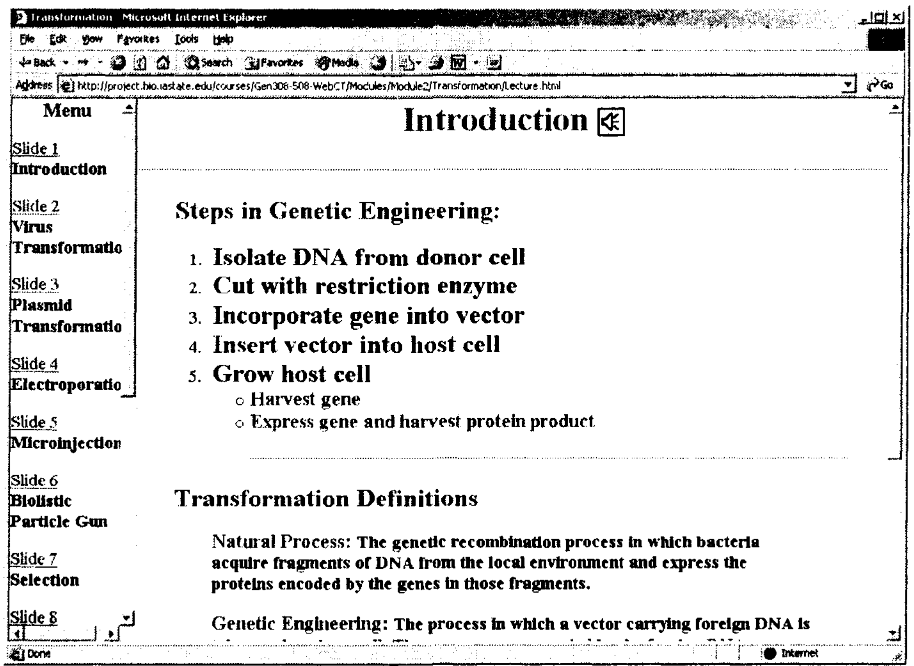

FIGURE 2. Example of on-line slide in the biotechnology class. The button to the right of the title takes a student to a streaming audio lecture utilizing RealAudio technology. As the audio lecture progresses, students use the menu bar to the left to progress from slide to slide.

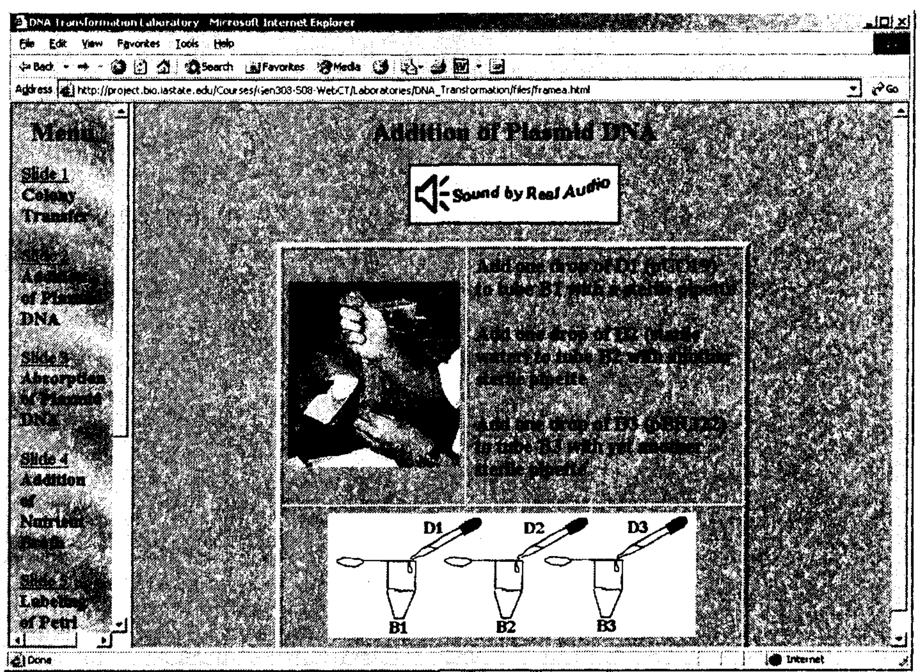

FIGURE 3. Example of an on-line authentic learning assignment in the biotechnology class. As with the on-line lectures (Figure 2), this assignment features a RealAudio lecture accompanying student progressing through the slides via the menu bar at left.

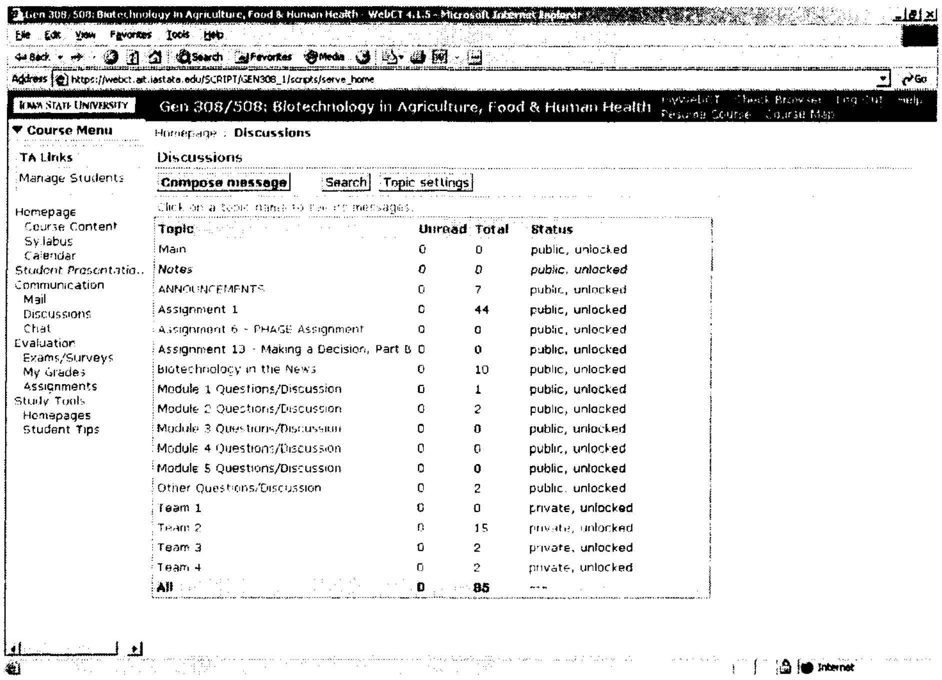

FIGURE 4. Example of Discussion Forum in the biotechnology class. Thirteen rooms have already been established for public discussion, and 4 private rooms for the cooperative learning groups that will participate in the PBL unit.

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applications (the latter focusing on the Human Genome Project). Graduate students either complete Module 4 or Module 5 plus a creative component (such as a lesson plan or a literature review), or complete Module 4 *and* Module 5 simultaneously. All modules are completed individually except for the PBL unit (Module 3). The five modules are as follows:

1) Principles of Molecular Biology (3 weeks)
2) Principles of Biotechnology (4 weeks)
3) Genetic Diseases (the PBL unit) (5 weeks)
4) Agriculture and Food (4½ weeks, simultaneous with Module 5)
5) Human Genome Project (4½ weeks, simultaneous with Module 4)

Module 3 utilizes PBL pedagogy for student learning about genetic diseases and genetic testing. One of the most interesting aspects of biotechnology is the ELSI raised by the technologies. In the case of the genetic diseases unit, the central ELSI question is whether genetic testing is beneficial in a situation where there is no cure for the genetic disease, such as with Huntington disease. The PBL approach allowed us the use this intriguing ELSI question to capture student interest and to motivate learning about the more technical aspects of the topic (nature of genetic diseases and genetic testing technologies). The learning objectives for the PBL unit are for the students to:

- Understand the nature and mode of inheritance of genetic diseases
- Gain an appreciation of the human cost of genetic diseases
- Understand the principles and technologies used in genetic testing
- Gain an appreciation of ethical, legal, and social issues associated with genetic testing
- Develop problem-solving skills
- Learn how to find and process information in Web-based databases

Huntington Disease

Best known for killing folk singer Woody Guthrie in 1967, Huntington disease (HD) is a progressive fatal neurological genetic form of choreatic hyperkinesias characterized by George Huntington (1872) in a family on Long Island. Huntington's work was not well known, however, until he was cited by Osler (1893), who wrote, "Twenty years have passed since Huntingdon *[sic]*, in a postscript to an every-day sort of article on chorea minor, sketched most graphically, in 3 or 4 paragraphs, the characters of a chronic and hereditary form which he, his father and grandfather had observed in Long Island...Several years ago I made an attempt to get information about the original family which the Huntingdons *[sic]* described, but their physician stated that, owing to extreme sensitiveness on the subject, the patients could not be seen." Interestingly, nearly 1,000 cases spanning 12 generations in the families Huntington studied on Long Island could be traced to two brothers named Bures who left Suffolk for Boston Bay in 1630 (Vessie, 1932). It is now believed that HD may have been responsible for the "dancing mania" of the Middle Ages that was interpreted as proof of practicing witchcraft and possession by demons, "a derise pantomime of the sufferings of the Saviour during crucifixion" (cited by Enersen, 2001). Religious violence during the French civil war prior to the Edict of Nantes in 1598 led the Bures family to emigrate from France to Essex and then Suffolk (Maltsberger, 1961; Critchley, 1973). HD is very rare in populations not of French ancestry.

HD is caused by a mutation in a gene (*HD*, on chromosome 4, region 4p16.3) coding for a protein called huntingtin (MacDonald *et al.*, 1992). Huntingtin is one of three proteins (the others are huntingtin-associated protein 1 and the $p150^{Glued}$ subunit of dynactin) which are responsible for accelerating transport of vesicles containing brain-derived neurotrophic factor (BDNF) along microtubules in neuron axons (Gauthier *et al.*, 2004). BDNF is an anti-apoptosis factor. Without proper BDNF transport throughout the length of the axon, the neuron is in increased danger of undergoing apoptosis, or cell death. Huntingtin may also be indirectly involved in increasing BDNF transcription by increasing the activity of BDNF transcription factors (Sugars and Rubinsztein, 2003). The results of increased neural apoptosis concentrated in the caudate nucleus, putamen, and globus pallidus are progressive chorea, rigidity, seizures, and dementia. HD symptoms can begin at any age, but the age of onset is most frequently between the ages of 30 and 40 (Chandler *et al.*, 1960). Once symptoms have begun, the average life expectancy of a HD patient is 17 years, though if the disease shows symptoms before age 20, the average life expectancy drops to 8 years.

The mutation responsible for HD consists of an excessive number of CAG (cytosine-adenine-guanine) repeats within exon 1 of the *HD* gene, leading to a huntingtin protein with too many glutamine residues, interfering with interactions between huntingtin, huntingtin-associated protein 1, p150^{Glued}, and BDNF. The number of CAG repeats is variable and is responsible for 65% to 71% of the variance of the age of onset of HD (Rosenblatt *et al.*, 2001). The normal *HD* allele contains 11 – 34 CAG repeats, with 36 or greater CAG repeats indicating a very high probability of exhibiting the symptoms of HD. Of all HD cases, approximately 95% occur in the presence of 40 – 55 CAG repeats. Clinically, the presence of 27 – 35 CAG repeats is classified as "intermediate". The "intermediate" individual is at low risk himself or herself, but due to a phenomenon called "anticipation", his or her children may be at a significant risk (Creed, 1999). No differences in expression or age of onset have been reported between homozygotes (with two mutant alleles) and heterozygotes (with one mutant allele and one normal allele). There is, however, a direct correlation between the number of CAG repeats in a *HD* mutation and the average age of onset for individuals with that number of CAG repeats.

Anticipation is a phenomenon in which some patients experience the onset of HD at a significantly earlier age than their parent. When the mutant *HD* is inherited from a patient's father, the majority of individuals experienced the onset of symptoms slightly earlier than their father, while a significant minority experienced major anticipation leading to the onset of symptoms up to 24 years earlier than their father (Ridley *et al.*, 1988, 1991). The cause of anticipation is unknown. In some cases, *de novo* expansion of the CAG repeating region may lead to more severe symptoms in children of HD patients. Ridley *et al.* (1988) propose epigenetic mechanisms affecting the methylation of the genome during the imprinting process, while Myers *et al.* (1982) explain anticipation as selective non-breeding of individuals who succumb to early-onset HD. On the other hand, there may also be environmental factors affecting the age of onset. Wexler *et al.* (2004) found after extensive inheritance research on HD in Venezuela that the heritability of age of onset due to the *HD* gene was 38%, 25% of the variance in the onset of HD was due to other genes besides *HD*, and the remaining 37% of the variance in the age of onset was due to as-yet unknown environmental factors.

The mutant allele is inherited in a completely dominant fashion (Wexler *et al.*, 1987), but the progression of the disease depends on which parent the mutant allele was inherited from, suggesting the presence of an imprinting effect in which the DNA from one parent has been methylated, though this has not been shown conclusively. Patients who inherited the mutant HD allele from their father exhibited an earlier age of onset and faster progression of the disease than patients who inherited the mutant allele from their mother (reviewed in OMIM, 2005). Of late-onset cases, where the age of onset is 50 years old or older, 2/3 inherited the mutant allele from their mother (Myers *et al.*, 1983). Interestingly, Myers *et al.* (1983) proposed that the expression of the mutant *HD* might be affected by some heritable extrachromosomal (mitochondrial) factor that is inherited only from an individual's mother. Boehnke *et al.* (1983) proposed either a mitochondrial factor or an X-linked gene. However, like imprinting, such factors remain strictly hypothetical.

There are no dependable pharmaceutical treatments for HD. Commercial treatment currently consists of symptom management. Several experimental drugs are in the *in vitro* testing phase; a few have moved into the animal testing phase (using transgenic mouse models of HD). These include minocycline, an apoptosis inhibitor (Fink *et al.*, 1999; Chen *et al.*, 2000); trehalose, which inhibits the aggregation of polyglutamine proteins in the brain (Tanaka *et al.*, 2004); and rapamycin, which is sequestered in polyglutamine protein aggregates, triggering the breakdown of these polyglutamine proteins by the cells themselves

(Ravikumar *et al.*, 2004). Neurogenesis through the use of embryonic stem cells shows great promise, but also stirs political controversy.

HD is the classic example of one of the great ethical dilemmas of the post-Human Genome Project era, created by the widening gap between what we can diagnose and what we can treat. There is a DNA test to determine the number of CAG repeats in the *HD* gene, and thus diagnose an individual with HD long before any symptoms have manifested themselves. A positive result usually means that the individual can look forward to an early and unpleasant death, and currently there is nothing he or she can do about it. In *Œdipus Rex*, Œdipus is destined to kill his father and marry his mother, no matter how much he and his family may try to thwart fate. The blind prophet Teiresias confronts Œdipus, saying, "When wisdom brings no profit, to be wise is to suffer" (Sophocles, *c.* 430 B.C.E./1982, p. 41). Œdipus' suffering due to wisdom cost him his eyes. Wexler (1992) refers to the HD testing dilemma as the Teiresias Complex, and re-states Teiresias' question thus: "Do you want to know how and when you are going to die, especially if you have no power to change the outcome? Should such knowledge be made freely available? How does a person choose to learn this momentous information? How does one cope with the answer?" The suffering of an individual with the knowledge that they will die of HD costs them their peace, their mental well-being, and possibly their life – there are cases of individuals who have tested positive for HD who have subsequently committed suicide (B. LeRoy and D. Bartels, personal communication).

The PBL Unit – General Overview

The Problem

In the PBL unit, student cooperative learning groups will be faced with the problem of a man, named Robert, with a family history of HD. Initially the students are presented with Robert's story:

> <u>Case Overview</u>
>
> Robert is an airline pilot who works for a commuter airline. He is married to his high school sweetheart, Angela. Angela has a college education but is not currently working outside the home so that she can take care of their four-year-old daughter, Andrea.
>
> Robert is 33 years old. He is increasingly aware of an unpleasant family heritage, Huntington's disease. His mother, Martha, began experiencing early signs of the disease (confusion, periods of depression, and unreasonable outbursts of anger) when she was 34 years old. She ultimately died of pneumonia, a complication of the disease, at age 50. As the disease progressed, she became increasingly incapacitated and she spent the last few years of her life in a nursing home.
>
> Robert recently learned that there is a presymptomatic genetic test that could tell him whether he is carrying the Huntington's disease defect. He wonders whether he should have the test performed.
>
> <u>Family History</u>
>
> *Robert* – Age 33. He was 15 when Martha's symptoms first set in. Met Angela when he was 16 and she was 15. Married Angela at 22 after he had finished college and she had one year left. He was Air Force ROTC, finished his service at 27 and has taken a job with a commuter airline. He was 28 when the family had to place Martha in the nursing home with what they initially thought was early-onset Alzheimer's. He was 29 when Angela had Andrea and when Martha was correctly diagnosed with HD.
>
> *Martha* – Died at 50 when Robert was 31. She was 19 when she had him. She was 47 when she was correctly diagnosed (previously diagnosed with early-onset Alzheimer's). Her husband (Joseph) died of a heart attack when she was 45. She was 46 when she had to go to the nursing home, in part because Joseph was gone, Robert was always away, and Angela was working and couldn't spare the time to ensure Martha's well being. Martha's parents both died in a car accident when she was 10 and she was raised by her Mom's sister who showed none of the signs of HD.

Angela – Age 32. She met Robert when she was 15. Married at 21, with one year left in college. She was 28 when she had Andrea.

Andrea – Age 4. She was 2 when Martha died, so has only incomplete memories of Martha.

Text-based PBL Unit: An Overview

The PBL unit has been used with students in two different forms. The first manifestation of Robert's dilemma was as a text-based unit (Figure 5). Not only was Robert's story text-based, but all the authentic learning activities were text-based as well, and aside from a few on-line lectures, there was no multimedia component to the PBL unit at this time. Assessment, in addition to the authentic learning activities, was conducted initially (Fall 1998 – Spring 1999) through a pre-unit exam and a post-unit exam (see Appendix A), though the pre-unit exam was discontinued for Fall 1999 through Fall 2003.

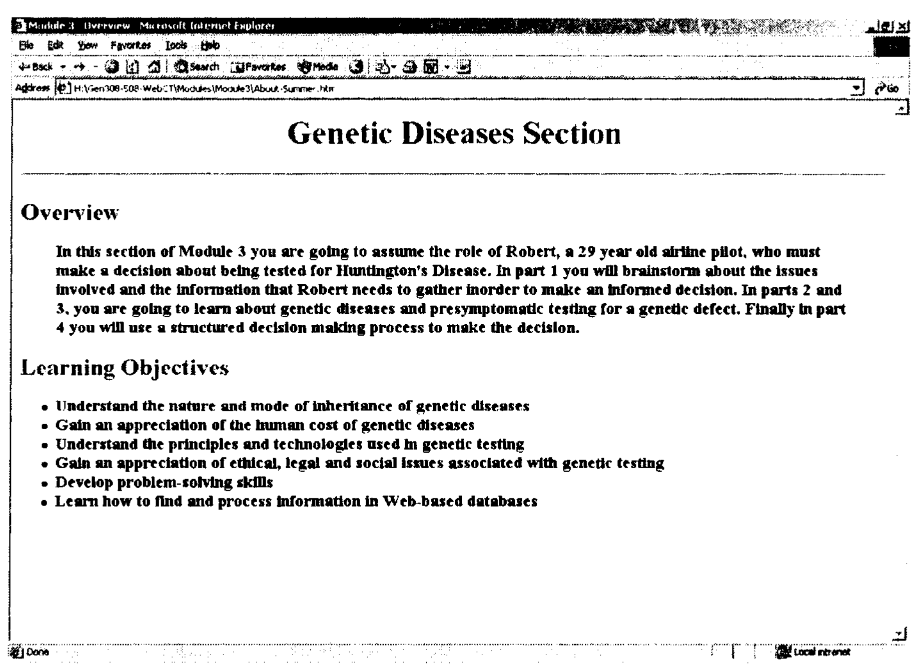

FIGURE 5. Introductory slide to text-based PBL unit (Fall 1998 – Fall 2003).

Authentic learning activities initially (Fall 1998 – Spring 1999) included three research papers that the students completed in cooperative learning groups. These three papers were titled "Defining the Issues", "Gathering Information", and "Solving the Problem". These three learning activities are detailed extensively in the literature (Cheaney and Ingebritsen, 2005), and in Chapter 4. Beginning in Fall 1999, "Gathering Information" was discontinued and replaced with two papers, "Genetic Diseases" (completed individually) and "Genetic Testing" (completed in cooperative groups). These two assignments are also described in more detail in the literature (Cheaney and Ingebritsen, 2005), and in Chapter 4. A side-by-side comparison of these two text-based formats can be seen in Table 2 in Chapter 4.

Our research on the text-based PBL unit includes analysis of low-level learning (as defined by Bloom *et al.*, 1956; Wright *et al.*, 1998; Cruickshank and Olander, 2002) by using on-line PBL in the form of student performance on the multiple-choice post-unit exams (and pre-unit exams in the case of the initial version of this unit). We also analyzed higher-order learning by analyzing student performance on the authentic learning activities, and student attitudes towards the PBL unit based on their evaluations of the unit. Our findings and their implications are discussed in Chapter 4.

Robert's World: An Overview

In 2004, the PBL setting was re-designed in cooperation with colleagues from the Department of English (D. Fisher and D. Russell) to create a multidimensional immersive PBL environment. The hope was that the inclusion of such items as videos with actors and experts, physical artifacts, and links to various databases and articles in an environment that allows exploration in a variety of virtual nooks and crannies would provide a more authentic experience for students and a context in which initially abstract concepts were transformed into a more nuanced form of understanding (Engeström, 1999). We believed such an immersive environment would provide an aspect of learning about both genetic diseases and genetic counseling that transcends the traditional college experience of limited applicability outside the university setting (Pardoe, 2000). In other words, the problem was being placed in a subconscious context in which the students would become more deeply involved with, which would increase their capacity to learn through role-playing "real" people (Broudy, 1976; Bransford and Schwartz, 1998; however, for an opposing view, see White and Welford, 1987). We believed that this would help them to develop more creative and critical thinking about the disciplinary material presented in the case, material which would be transformed "into a complex object, into a new form of practice" (Blanton, 2003). We also believed this would help generate a broader understanding of the various interrelated stakeholders who were impacted by the central character's decision, generate transferability of understanding to other situations, and develop student metacognition useful not just in this case study, but in all their educational experiences and in lifelong learning in decades to come.

The result of this collaboration was "Robert's World" (http://weblearning.engl.iastate.edu/RobertsWorld/; username="guest"; password="guest"). Robert's World consists of a central hub with a user interface that looks like a map of a city (Figure 6). From this hub students can navigate back and forth to and from several locations corresponding to various aspects of Robert's life (home, work, insurance company, genetic counselor's office, genetic testing lab, and library). The videos, assignments, and physical artifacts (such as medical forms, insurance files, and laboratory records) can be accessed from these several sites. Videos include interviews with actors playing the parts of the major characters, and interviews with real-life experts in the fields of bioethics, genetic counseling, genetic testing, and insurance. In addition, external links provide students with access to extensive amounts of information, especially medical/genetic information, and legal information on what federal and state laws say (and do not say) about asymptomatic diagnoses of genetic diseases. The various areas of Robert's World and the contents of each are reviewed in more detail in Chapter 5.

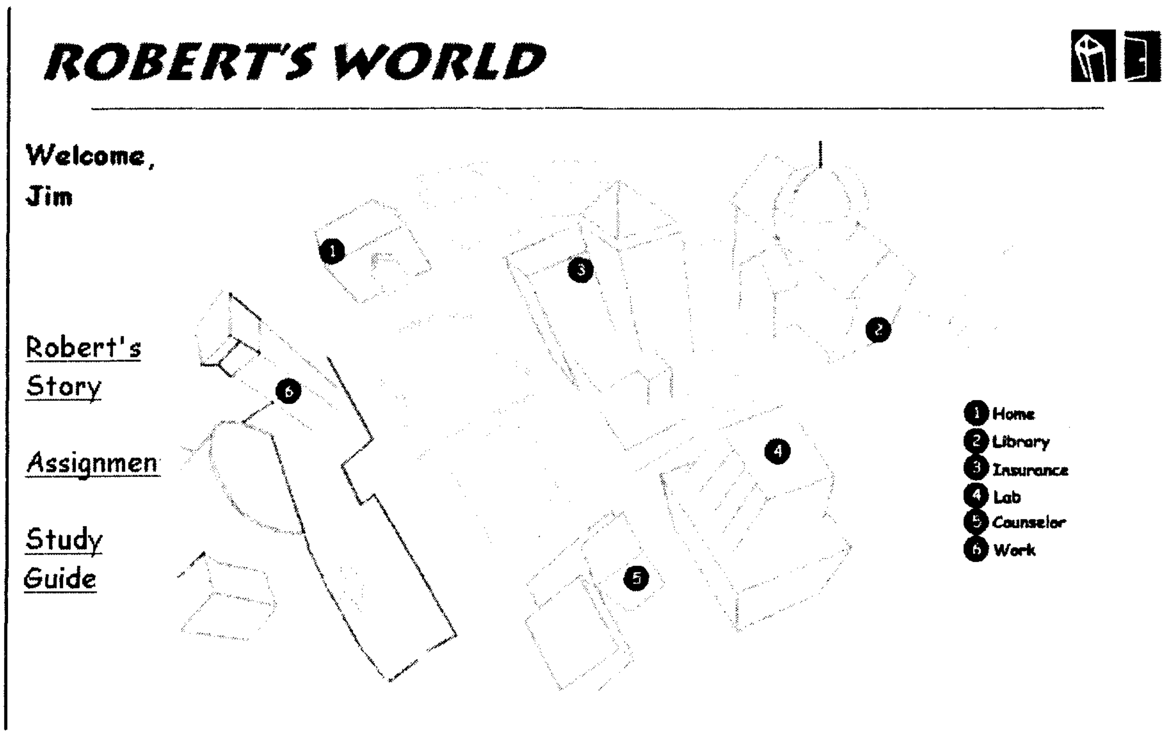

FIGURE 6. Layout of Robert's World (http://weblearning.engl.iastate.edu/RobertsWorld/; username="guest"; password="guest"). From this hub, first used in Spring 2004, students can link to various facets of Robert's life (home, insurer, genetic testing lab, genetic counselor's office, and work) and a central information hub (library) to gather information needed to provide Robert with advice on whether or not to seek a pre-symptomatic DNA test for Huntington disease. Information on the various sites within Robert's World is discussed extensively in Chapter 5. ***Note:*** **This figure is identical to Figure 7.**

Authentic learning activities imbedded within Robert's World (beginning in Summer 2004, the second semester of use) include the "Defining the Issues", "Genetic Diseases", and "Genetic Testing" papers carried over from the text-based PBL unit (described in detail in Chapter 4). "Genetic Diseases", formerly an individual assignment, now became a cooperative learning group assignment. "Solving the Problem" was re-christened "Making a Decision", in recognition of the fact that Robert's dilemma has no right or wrong answer (and indeed, a focus on "solving" a problem often short-circuits the entire learning and writing process (Galbraith and Torrance, 1999)). In "Making a Decision", each cooperative learning group was assigned one of five chief stakeholders (Robert, Angela, Andrea, Robert's employer (the airline), or Robert's (employer-based group) health insurance company). Groups role-played the role of each stakeholder advising Robert on whether or not he should have the DNA test performed, when, and who should be involved, based on their own self-interest. For instance, the insurance company needed to demonstrate a concern for their bottom line and premiums charged to the airline balanced against the possibility of Robert incurring catastrophic health care costs.

Two new assignments also appeared with the adoption of Robert's World. "Genetic Counseling" was an individual assignment designed to demonstrate the transfer of their understanding of genetic diseases and genetic testing to a quite different genetic disease (mutations in the *BRCA1* DNA-repair gene are one cause of early-onset familial breast cancer, but are far from the only cause of breast cancer; plus, a mutation in *BRCA1* does not doom one to breast cancer – it only increases the possibility of developing breast cancer – and, unlike HD, breast cancer is not automatically fatal, although it is the 3rd most common cause of mortality among American women).

The second of the new authentic learning activities, "Describing the Disease", is a group assignment in which students role-play Robert discussing his research about HD and his feelings about the possibility of having the disease with Angela. Students get to demonstrate their own research on the inheritance, genetic and physiological characteristics of HD, and ELSI surrounding HD, and transfer all that research in a unique way – they get to translate the highly technical information they have discovered into layperson's language. Writing for a layperson leads students to relate their subject material in a format more understandable and less technical, creating a shift in their perception and understanding of the material (Ackerman, 1990a; Flower, 1994). Presenting formal (or technical) information in informal language can clarify students' thinking, activate prior knowledge, and contribute greatly to learning new concepts (Healy and Barr, 1991). As Nobel laureate Peter Debye once remarked, "You don't really understand something until you can explain it to the man on the street" (cited in Styer, 2002). Both of these student assignment papers are described in more detail in Chapter 5.

Our research on Robert's World focuses on higher-order learning (as defined by Bloom *et al.*, 1956) in the immersive PBL unit by analyzing student performance on the authentic learning activities. We believed that the immersive and multidimensional nature of Robert's World would make students more involved and engaged in the material from both a scientific/technical aspect and an ELSI aspect. We also looked at student exam scores to determine whether PBL compromises lower-level learning, and analyzed student attitudes towards the Robert's World both numerically and anecdotally based on their evaluations of the unit. Our findings and their implications are discussed in Chapter 5.

Writing and Scientific Literacy

Assessment: The Importance of Writing

Assessment of authentic learning experiences are a controversial part of the literature surrounding PBL. It is difficult to devise a strictly objective means of assessing student performance in learning material. Assessments of authentic learning experiences must involve problems and provide opportunities where the complexity of the student's thinking process is exhibited (Wright *et al.*, 1998). From the instructor's point of view, this is quite different from writing questions for a lower-order multiple-choice exam. From the student's point of view, this is quite different from regurgitating facts that were crammed the night before. As discussed in the previous section, we believe that writing provides an ideal way for students to demonstrate application (problem solving), analysis of relevant issues, synthesis of organization, and evaluation of the ELSI surrounding the topic, all of which are considered "higher-order" learning in the taxonomy developed by Bloom *et al.* (1956).

Writing forces students to internalize facts, rather than just retrieving them. Writers are then "attempting to probe for analogues and contradictions, to form new concepts, and perhaps even to restructure their knowledge of the subject" (Flower and Hayes, 1980). The interactions and feedback (discourse) between the requirements of the subject matter and the requirements of translating it into language facilitates the development of higher-order learning as new relationships between topics are constructed (Raimes, 1980; Berthoff, 1982; Griffin, 1983; Galbraith, 1999; Miller, 1999).

In addition, the importance of being able to write effectively in one's post-educational career continues to grow. In industry, academia, and government, scientists are often surprised at (and ill-prepared for) the amount of writing involved in their jobs (Enke, 1978).

A 1989 survey of biotechnology companies indicate that these companies rank "communication skills" (including writing) second in importance only to "relevant work experience" as the most important skill in prospective employees, and far ahead of chemistry background, recommendations, degree, broad-based biology background, GPA, or highly focused biology expertise in terms of importance (Davis *et al.*, 1989). Other studies reinforce the view that the ability to write effectively increases one's prospects for employment in science (Pollack and Godwin, 1983), while an inability to write effectively decreases one's prospects for employment or promotion (Hairston, 1981). Part of this may be due to the fact that so few graduates are capable of writing effectively (Healy, 1992; Kelly, 1992). And in one anecdotal case, the ability to write effectively may have led to the greatest honor in science. Richard Feynman claims that his classic paper on quantum electrodynamics (Feynman, 1948) contained "no fundamentally new results" but instead offered only a re-explanation of "old things from a new point of view" (Gleick, 1992). This paper, apparently a result of the discursive development of Feynman's intellectual disposition, rather than a single set of novel data, led in large part to Feynman's 1965 Nobel Prize in Physics.

The Importance of the Audience

Having recognized the importance of scientific writing, many researchers have explored models of how writing can help students internalize and understand important concepts as well as to effectively convey their understanding in the written word (reviewed in Klein, 1999). Flower (1985, 1994) encourages writers to consider the "rhetorical situation" that they face when they sit down to write. This rhetorical situation consists of three parts which the writer must consider. The first of these is the writer's purpose (which consists not only of what task the writer wishes his or her paper to do (inform, as in "Describing the Disease"; persuade, as in "Making a Decision", *etc.*) but also what the final product should look like in form). The second element concerns the writer himself or herself. The writer must consider how he or she wants to sound or appear to the reader. Third is the writer's intended audience, in which the writer considers what the reader wants to learn from the paper. Expert writers keep all three parts in mind, often subconsciously, and write reader-based prose, whereas novice writers often drift or deviate as they write and create writer-based prose (Flower and Hayes, 1980). Siler (1997) proposes a similar structure of the rhetorical situation, while splitting the purpose of the paper into the intent of the author and the demands of the subject material.

Prain and Hand (1996a) propose a model in which the rhetorical situation consists of five elements: the topic, type or genre of paper, the author's purpose, the audience, and the method of text production. The first three and the last of these elements correspond to the purpose of the writer as explored by Flower (1985), but allow the writer to expand the possibilities of how to transmit information to the reader, in some cases altering the author's requirements of how to view the subject depending on the demands of the writing form (Rillero, 1999).

The one part of the model explicitly conserved between the models of Flower (1985, 1994), Prain and Hand (1996a), and Siler (1997) is the importance of the audience. In too many situations, the only audience of a student's paper is the instructor. However, in a graduate's post-educational career, he or she will be writing for a wide range of individuals with varying levels of education, experience, or needs (Rice, 1998). The exploration of a topic for different audiences motivates the author to develop new connections between topics and to clarify his or her understanding of the topic (Ackerman, 1990b; Flower, 1994). In many cases, the identification of the audience will factor into the choice or presentation of the topic.

In a cooperative learning environment such as the PBL unit, the students are writing not only for the instructor but also for their classmates, a very powerful type of audience for any writer. In science, the gold standard for evaluation of professional writing is peer-review. In the classroom, responses by fellow students are often as effective as teacher-evaluation in improving a student's writing effectiveness as well as his or her attitudes towards writing (Jones, 1977; Thompson, 1981; Rice, 1998; however, for an opposing viewpoint, see Hayes and Nash, 1996). Student groups in Robert's World often divide the labor such that certain students are responsible for certain parts of the paper, which are then reviewed and evaluated by their groupmates. In such an arrangement, the final step (other than proofreading) is to combine everybody's work into a collective paper that will be submitted. In addition, in "Making a Decision", students role-play their assigned stakeholder and post summaries of their decision and details about its justification in the class Discussion Forum, which is then discussed by the other "stakeholders", all in character. In some cases, heated arguments have arisen as the "stakeholders" debated the pros and cons raised in discussions and critiques about each other's posts.

Once an audience (or audiences) has (have) been identified (often this is stated in the assignment, such as Angela in "Describing the Disease" or a woman with a family history of breast cancer in "Genetic Counseling"), that audience can be analyzed to determine the differences between the writer and the audience. According to Flower (1985), this analysis can be broken down into three concerns:

1) *Audience knowledge*. What does the reader know, and what does he or she need to know in order to understand the writer?

2) *Audience attitudes*. How does the reader's historical, emotional, or moral background affect his or her reception of the information transmitted by the writer?

3) *Audience needs*. What *useful* information can be transmitted, and in what form should this transmission take? In an educational setting, this usually takes the form of a demonstration that the writer has internalized, thought about, reorganized, and made connections among and between subject matter.

The Role of the Audience

When a writer writes his or her paper, he or she is communicating to the audience, who is as equally important to the message as is the writer. For instance, in the early days of military wireless communication (World War II and Korea), Army intelligence and Office of Strategic Services (an agency that was re-organized by President Truman into the CIA and the National Security Council) researchers dealt with the problem of radio communications between headquarters and soldiers or spies in the field (Flower, 1985). The generator of communication must encode his or her thoughts into language (or other means of encoding, such as pictures or equations). The receiver then decodes the message and attempts to deduce meaning. Obviously, if the sender and receiver have different "code books" (different ways of looking at the information), the meaning will not be conveyed in the way the sender intended (imagine the Axis code-breakers trying unsuccessfully to deduce meaning in messages transmitted by Navajo code-talkers). The message can also be altered through "noise", either linguistic (grammar, poor organization, or inappropriate metaphors), physical (entropic effects on the message), or psychological (distractions).

How does the reader's decoding process work? According to constructivist thought, forces such as social context, language, the base of activated knowledge, and the reader's purpose and goals act upon the reader in a mirror fashion to those acting upon the writer (Flower, 1987; Bereiter and Scardamalia, 1993). These forces result in discursive construction upon the foundation of the text (or equations, pictures, and so forth) that may be quite different than that intended by the writer (Flower and Hayes, 1984; Flower, 1988; Gee, 1989; Bloome and Bailey, 1992; Flower, 1994).

In addition, the reader is not capable of remembering everything contained within a message. The human mind can only handle 7 ± 2 bits of information at any given time, depending on the nature of the information (reviewed in Miller, 1956). Our ability to communicate vocally is not much better. The human voice can only process 23 to 25 bits of information per second. As a result, Miller (1956) refers to the human mind and human forms of communication as an "informational bottleneck."

However, humans are capable of avoiding this bottleneck by recoding bits of information into "chunks." In other words, as bits of information build up pass the critical limit of 7 ± 2, the human mind automatically reassembles these bits into larger wholes that only count as 1 against the critical limit (Miller, 1956). For example, individual letters are assembled by the human mind into words, which are then assembled into sentences, which are converted by the reader's discourse into thoughts.

As a result, when a reader reads a piece of writing, rather than remembering everything in the paper, the reader draws inferences from the reading. Flower (1985) defines *inference* as "a new idea we *create* from previous ideas." These inferences may consist of adding the new information to a pre-existing chunk, or creating a new chunk from the ideas presented in the paper, whether or not they are intended to be lumped together. In other words, readers remember not what the writer tells them, but what the reader tells himself or herself, using the writer's ideas to form their own concepts (Bransford, 1979; Flower, 1985; Haas and Flower, 1988). The reader constructs his or her own meaning from the writing, which may or may not be the same as what the writer intended.

How are these inferences drawn? Readers use four strategies to generate these inferences (Bransford, 1979; Flower, 1985, 1990). First, the reader will attempt to fit these new ideas into a pre-existing context. This context may be constructed from the reader's emotional, social, historical, or ethical background (Reder, 1980), and may be something that is totally alien to the writer's context, or even alien to the reader's context when faced with different information or the same information in a different setting (Kintsch, 1974; Freedman *et al.*, 1987). This context is often dictated by the reader's individual goals or needs (Pichert and Anderson, 1977; Meyer, 1982), and may even blind the reader to what is actually contained in the message. To use another World War II example, when Hitler was presented throughout 1944 with intelligence reports summarizing Allied communications intercepted by the Germans, he interpreted them as confirming his pre-conceived notions that the Allies would invade France at Dunkirk or Calais, rather than Normandy. As a result, despite all the intelligence they had about the Allied invasion, the Germans were still surprised when the Allies landed at Normandy on D-Day. Second, the reader makes predictions and develops expectations based on previous cues or teasers, or because of the structure of the writing (Flower, 1985). Third, the reader organizes the presented ideas into gists. These gists correspond to psychological chunks that have been altered by the ideas presented in the writing (Farnham-Diggory, 1972; Kintsch and Vipond, 1979). Fourth, readers develop a subconscious hierarchical structure built around these gists as they see them (Bartlett, 1932; Mandler and DeForest, 1979; Meyer *et al.*, 1980; Meyer, 1982; Winograd, 1984). However, there is no guarantee that recoding bits of information into chunks can be reconstructed by the reader into a contextual whole (Newell, 1986). This is the source of many of the disconnects between the reader's inferences and the writer's intended inferences, such as a demonstration (or lack thereof) of relevance to the subject at hand.

Effective writers are able to manipulate the strategies for drawing inferences to their own advantage, by explicitly stating main ideas and expected conclusions, focusing each paragraph on one particular main idea in a hierarchical structure, and use an expected pattern of organization (Flower, 1985). These patterns may be classified as the TRI pattern (the topic-restriction-illustration pattern), the problem-solution pattern (where a rhetorical question is asked, and then answered), and chronological order (Becker, 1965; Christensen, 1965; Larson, 1971). Each of these strategies for writing can lead readers to draw inferences more closely to what the writer intends, and each involves certain cues in sentence structure that lead the reader to expect an organization that will respond to his or her needs (O'Hare, 1973; Flower, 1985). Incorporation of these strategies into establishing an empathic link with the reader through the development of shared goals demonstrates an attempt by the writer to direct the reader's inferences towards those more compatible with the writer's inferences, and contribute to the transformation of the transmitted ideas in the minds of both the writer and the reader (Holtzman, 1970; Clark and Clark, 1977; Flower, 1985, 1990).

Reader-Based Prose

The strength of writing in science lies in its ability to create a transformation of knowledge or even the construction of new knowledge by creating links among different elements of the discourse of the material (Galbraith, 1999). This discourse can be effectively managed by dealing directly with the metacognition of the construction of this academic discourse – the goals, strategies, and awareness of this transformation (Flower, 1990). An integral part of this metacognition gearing his or her writing towards that audience, transforming "writer-based prose" into "reader-based prose" (Flower, 1985). This gearing can itself generate a great deal of transformation of the material within a student's mind (Hand *et al.* 1999). This transformation increases with the variety of contrasting contexts and purposes connected to different writing activities (Hand and Prain, 1995; Prain and Hand, 1996b). However, instructors can only develop an environment conducive towards that transformation of prose. The onus remains on the student to take the information and apply it in such a way that the writing assignment will be valuable to his or her science education.

CHAPTER 4

PROBLEM-BASED LEARNING IN AN ON-LINE COURSE: A CASE STUDY

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Abstract

Problem-based learning (PBL) is the use of a "real world" problem or situation as a context for learning. The present study explores the use of PBL in an on-line biotechnology course. In the PBL unit, student groups dealt with the ethical, legal, social, and human issues surrounding pre-symptomatic DNA testing for a genetic disease. Issues concerning implementation of PBL in the on-line environment are discussed, as are differences between on-line PBL and face-to-face PBL. This study provides evidence to suggest that PBL stimulates higher-order learning in students. However, student performance on a lower-level exam testing acquisition of factual knowledge was slightly lower for PBL students than for students who learned the same material through a traditional lecture-based approach. Possible reasons for this lower level of performance are explored. Student reactions and feedback to the PBL format yield more insight into issues surrounding the implementation of PBL in the on-line environment.

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Introduction

Problem-based learning (PBL), also known as case-based learning, is an increasingly integral part of education reform in the United States and around the world, especially in the medical and social sciences, and in pre-professional and professional programs (reviewed in Michel *et al.*, 2002). While there is no universally-accepted definition of problem-based learning in the literature (Maudsley, 1999), the essence of PBL can be summarized as the use of a "real world" problem or situation as a context for learning (Morgan, 1983; Barrows, 1985; Boud, 1985; Duch, 1995; Domin, 1999; Michel *et al.*, 2002). The purpose of PBL is to encourage student development of critical thinking skills, a high professional competency, problem-solving abilities, knowledge acquisition, the ability to work productively as a team member and make decisions in unfamiliar situations, and the acquisition of skills that support self-directed life-long learning, self-evaluation, and adaptation to change (Engel, 1991; Albanese and Mitchell, 1993; Ryan and Quinn, 1994). In PBL, this is achieved by using situations or problems presented in class that resemble reality. PBL is a student-centered constructivist approach to learning which facilitates the construction of a conceptual network of knowledge in students, which can then be applied in a wide range of practical settings (Creedy and Hand, 1994; Cruickshank and Olander, 2002). In many cases, the realistic problems used in PBL studies may not have a right or wrong answer. Instead, PBL works through five cognitive areas to stimulate learning:

1) activation of students' prior knowledge
2) elaboration of prior knowledge through cooperative discussions
3) restructuring of knowledge to fit the problem presented; construction of an appropriate semantic network through internal discourse
4) learning in the scaffolding context of a real-world problem
5) emergence of epistemic curiosity due to relevance of problem

(Schmidt, 1993)

In the PBL environment, students should be allowed to analyze the problem in its own and the student's context and environment (Coles, 1990, 1991) and to construct a method to arrive at a detailed analysis, if not a final conclusion (this process is sometimes referred to as "situation-based learning"; Dockett and Tegel, 1993; Russell *et al.*, 1994). Care must be taken to ensure that students are not forced to follow one particular path to a predetermined conclusion (sometimes referred to as "solution-based learning" (Cowdroy, 1994); however, for an opposing viewpoint on the importance of actually *solving* the problem, see de Shazer, 1985). In PBL, the focus is on the *process*, not the *product* (Patel *et al.*, 1991; Margetson, 1994; Shannon and Brine, 1994).

PBL is extremely consistent with constructivist philosophy. Constructivism (of which there are many different flavors) is, in the general sense, a Kantian philosophy (also heavily influenced by Descartes) which views knowledge as something the learner must uniquely construct for and by himself or herself in order to have a personal understanding of their own interaction with their environment (Kant, 1800/1974; Dewey, 1929; von Glasersfeld and Smock, 1974; Hilgard and Bower, 1975; Ryle, 1975; Blais, 1988; von Glasersfeld, 1989; Schmidt, 1993). Savery and Duffy (1995) identify three fundamental constructivist principles: understanding comes from our interactions with the environment (but not in the behaviorist stimulus-response fashion), cognitive conflict stimulates learning (expanded upon by Willingham, 2004), and knowledge evolves through social discourse and evaluation of the viability of individual understandings. All these principles are explicitly fulfilled through PBL. PBL instructors, as a result, become facilitators, coaches, and mentors, rather than the positivist stereotypical "fount of knowledge" (Collins *et al.*, 1989; Mullins, 1994; Russell *et al.*, 1994; Mierson, 1998). PBL is pedagogically suited to many different types of constructivism, including Piagetian cognitive constructivism (Kanuka and Anderson, 1999), radical constructivism (in which PBL can be incorporated with cognitive apprenticeship) (Collins *et al.*, 1989; Duffy and Bednar, 1991; Honebein *et al.*, 1993), situated constructivism (crisscrossing landscapes) (Spiro and Jehng, 1990; Molenda, 1991; Spiro *et al.*, 1991), and co-constructivism (in which PBL can be incorporated with reciprocal teaching) (Shunk, 2000).

PBL is typically conducted using cooperative learning groups (Anderson and Henley, 1994; White, 1996). Ideally, cooperative student learning groups should be as heterogeneous as possible to maximize the breadth of experiences and academic skills available to the group (Cuseo, 1996). Nevertheless, the PBL paradigm can provide sufficient scope for individual study disciplines to be developed (Navarra *et al.*, 1993; however, the opposite viewpoint is implied by Tolnai, 1991).

PBL is usually conducted in a face-to-face setting. Less is known about the use of PBL in the electronic-based distance-education "virtual classroom", due to the relative novelty of electronic-based distance education. Klemm (2002) found that cooperative learning case study groups thrive in the electronic environment; however, Klemm's "case studies" were actually reviews of journal articles, and computer conferencing was used as an adjunct to face-to-face meetings between students in a traditional class. The Internet, however, allows a different kind of class experience that doesn't require students to ever meet each other in person. The versatility of the Internet, combined with its cost-effectiveness in overcoming the geographic limitations of the traditional university, presents educators with an unrealized potential to produce pedagogically- and scientifically-sound authentic learning experiences, including PBL, that allow for multidisciplinary projects, cooperative learning groups, flexible scheduling, and authentic assessments in distance education courses. They may revolutionize, supplement, complement, and enrich science education, both at a distance and in the traditional college setting.

Design of the Problem-Based Learning Unit and Assessment

A PBL unit has been used in several versions in an on-line undergraduate/graduate course entitled "Biotechnology in Agriculture, Food and Human Health". This is a three-credit survey course that covers technology and applications of biotechnology as well as ethical, legal and social issues (ELSI) associated with its use. When first conceived, the principal student market for the class was considered to be educators. However, since then, the bulk of the students have been a mix of traditional undergraduate and graduate students majoring in molecular biology or genetics or working in an on-campus lab, professionals working for seed or other biotechnology companies (often these students have a business rather than a science background), and farmers who want to learn more about the seeds they are planting and harvesting. There have been other students from all walks of life, including military personnel, lawyers, engineers, and an assistant state secretary of agriculture. Students are geographically diverse, with nearly every U.S. state represented, as well as students logging in from Canada, Germany, and Kenya. The course is offered three times per year, and the number of students typically ranges from 15–30 students per semester, with a typical 25–30% drop rate between the beginning and end of the semester.

The course consists of on-line audiovisual lectures that are modeled after lectures in a face-to-face classroom (utilizing on-line slides accompanied by a streaming audio/visual lecture), authentic learning assignments, and reading assignments in a required textbook and from various on-line resources. Approximately 60% of the grade in the course is based on authentic learning activities and the other 40% is from on-line exams based on content in the on-line lectures and reading material. Exams are password-protected and require the presence of an approved proctor (such as a county extension agent) to prevent student cheating. Within the class architecture, students can communicate with the instructor and with each other through an in-class e-mail system, a bulletin-board-style discussion forum, and both private and public chat rooms.

We decided to use PBL pedagogy for a 5-week unit about genetic testing technologies. One of the most interesting aspects of biotechnology is the ethical, legal and social issues (ELSI) raised by the technologies. In the case of the genetic testing unit the intriguing ELSI question is whether genetic testing is beneficial in a situation where there is no cure for the genetic disease. The PBL approach allowed us the use this interesting ELSI question to capture student interest and to motivate learning about the more technical aspects of the topic (nature of genetic diseases and genetic testing technologies).

In the PBL unit, students are asked to think about a fictional 33-year-old man named Robert. Robert's mother died of an incurable fatal neurological genetic disease called Huntington disease (HD). Huntington disease is caused by a defect in a gene (*HD*, on chromosome 4) coding for a protein called huntingtin. This defect is inherited in a dominant fashion (which means that inheritance of just one form of the abnormal gene usually leads to the development of HD). Thus, assuming there is no history in his father's side of the family, Robert has a 50% chance of having inherited the abnormal form of *HD*. Symptoms are classically manifested as progressive involuntary spasms and dementia. The age of onset is variable, but usually occurs between the ages of 15 and 60, depending on the severity of the defect. A review of more technical information about HD can be obtained from the National Center for Biotechnology Information's Internet site (http://www.ncbi.nlm.nih.gov/entrez/dispomim.cgi?id=143100). Robert's mother began exhibiting HD symptoms at the age of 34, and survived for 16 years before succumbing at 50. Despite the lack of a treatment or cure for HD, there is a pre-symptomatic DNA test to determine the nature of a patient's *HD* gene. A positive result usually means the patient can look forward to an early and unpleasant death, and currently there is nothing he or she can do about it.

The ultimate student objective of the class activity is to make a decision about whether Robert should undergo pre-symptomatic DNA testing for HD. Student groups role-play various stakeholders in Robert's decision (such as Robert himself, his wife, his 4-year-old daughter, his employer, and his insurance company) and decide over the course of the unit through meetings, assignments, and research, whether to advise the man to take the test or not. The learning objectives for the PBL problem are as follows:

- Understand the nature and mode of inheritance of genetic diseases
- Gain an appreciation of the human cost of genetic diseases
- Understand the principles and technologies used in genetic testing
- Gain an appreciation of ethical, legal, and social issues associated with genetic testing
- Develop problem-solving skills
- Learn how to find and process information in Web-based databases

Assessment of authentic learning experiences are a controversial part of the literature surrounding PBL. It is difficult to devise a strictly objective means of assessing student performance in learning material. Assessments of authentic learning experiences must involve problems and provide opportunities where the complexity of the student's thinking process is exhibited (Wright *et al.*, 1998). In the PBL unit that we are utilizing, assessment will be made through student performance on traditional exams consisting of a mix of multiple-choice and essay questions (see Appendix A), the students' presentation of different aspects of the problem through the process of writing papers, and their ability to internalize their understanding of biotechnology methods and ELSI in order to devise a novel genetic test or a new means for Robert to approach his problem and decision.

The cooperative learning groups for this unit were assigned into groups ranging from 2–3 in some semesters to 3–4 in some semesters, based on the number of students enrolled in the class. Groups were assigned as to provide a mix of students taking the class for undergraduate or graduate credit. Groups were also assigned to provide a geographic mix, to prevent some groups from having an unfair advantage if they decided to meet in person (if all members lived, for example, in the same county), while other groups were limited to chat rooms, e-mail, discussion forums, and other teleconferencing means. Geographic diversity in each group ensures that all groups must use the electronic means provided in the class architecture to hold meetings (though there was no attempt to prevent students from using external means of contacting their peers, such as standard e-mail or instant messaging). No attempt was made to separate students by innate ability, as reflected by GPA or overall grade in the class.

Two versions of the PBL unit were tested. In the preliminary version of the PBL unit (which was used for only two semesters) there were three assignments (Defining the Issues, Gathering Information, and Solving the Problem), which served as guiding problems for the unit. In addition, both a pre-unit exam and a post-unit exam were utilized.

In the "Defining the Issues" assignment, the student groups were asked to identify the issues involved in Robert's decision and the types of information that will be needed for Robert to make an informed decision. Each group posted a summary of the ideas developed on the course discussion forum. Students were encouraged not to conduct research on HD (yet), or to reach a decision (yet) on whether Robert should have the genetic test done. According to the learning taxonomy developed by Bloom *et al.* (1956), students were engaged in analysis of Robert's situation and applying their own previous knowledge and values to some of the concerns he will be facing.

In the "Gathering Information" assignment, student groups were required to write a short research paper about HD. The paper included information about clinical features of the disease, information about the gene, the genetic defect and the mode of inheritance of the disease, and information about genetic testing for Huntington's disease. Resources for the paper included on-line lectures and textbook reading assignments about genetic diseases and genetic testing technologies as well as Internet resources (*e.g.* molecular biology and genetics databases, informational Web sites). This assignment engaged students in comprehension of their research concerning HD and their ability to synthesize that research into a comprehensive whole.

In the "Solving the Problem" assignment, the student groups used a structured decision-making process to decide whether the individual should be tested for the genetic disease. The decision-making process involved identifying the stakeholders, brainstorming about possible options, considering the effect of various options on all of the stakeholders and finally choosing the "best" solution. The students then wrote a report on this decision, focusing on the logical defense and reasoning for their opinion. Students were not graded on their opinions *per se*, but on the persuasiveness and completeness of their arguments. Students applied their knowledge to the final situation and synthesized an appropriate response considering the varied and diverse concerns of the various stakeholders. In justifying their final recommendation, students evaluated the various arguments for and against Robert having the test done and all the variations thereof (such as when Robert should have it done, who should be involved in the decision, and so forth), and argued in defense of their decisions. These arguments reflected their own construction of values based on their research while recognizing those arguments' inherent subjectivity. According to Bloom *et al.* (1956), therefore, the "Solving the Problem" assignment can be classified under the application, synthesis, and evaluation domains.

Exam questions were taken from a test bank with several possibilities for each question. One possibility for each question was picked randomly by the examination software for the pre-unit exam and again for the post-unit exam. This ensured that questions were similar in difficulty for the pre-unit exam and the post-unit exam, and yet minimized the likelihood of students seeing the same question more than once. Exam questions tested understanding of inheritance patterns of genetic diseases and specific DNA technology techniques used in diagnosis of genetic diseases. Exam questions, along with possible answers and the correct answer, are listed in Appendix A.

A problem with the preliminary version of the PBL unit was the narrow focus on just one genetic disease (HD). Because of this the unit was revised by replacing the "Gathering Information" assignment with two other assignments, "Genetic Diseases" and "Genetic Testing", which gave the students a broader view of genetic diseases and DNA-based diagnoses. The other two assignments, "Defining the Issues" and "Solving the Problem", were used unchanged in the final version of the PBL unit. To date, this PBL unit has been used for 13 semesters.

In the "Genetic Diseases" assignment, students chose a genetic disease from a list of genetic diseases available at a NIH site. They were required to do research on the Internet in order to answer a set of specific questions about the disease and the characteristics of its manifestation, and the gene and genetic mutation associated with the genetic disease. This assignment was conducted as an individual student assignment. This assignment tests student comprehension of information gained from their research. This assignment also provides students with a background in other genetic diseases that can sometimes be manifested in added evaluation abilities when, in the "Solving the Problem" assignment, some students compare and contrast HD with the disease they picked for this assignment.

In the "Genetic Testing" assignment, the students are asked to design a novel pre-symptomatic genetic test for a fictional genetic disease, based on their understanding of DNA technologies used for genetic diagnoses. Resources for the two assignments included on-line lectures about genetic diseases and genetic testing technologies, textbook reading assignments and Internet resources. Unlike "Genetic Diseases", "Genetic Testing" was a group assignment testing their ability to synthesize a test using real technology for a fictional genetic defect.

The PBL unit was worth 28% of the grade in the course. Student assessment was based on written assignments (2/3 of grade) and a post-unit exam (1/3 of grade). The pre-unit exam was discontinued for the final version of the PBL unit. The test bank for post-unit exam questions was unchanged from that used in the earlier version. There was an added question in the post-unit exam about the legality of an action by Robert's employer or insurance company predicated on his testing positive for HD (see Appendix A). This question required students to research the legal basis for their answer on-line (so this question is referred to as the "open book" section, even though there is no physical book involved in the students' research for this particular question). Table 2 summarizes the main characteristics of the two versions of the PBL unit.

TABLE 2. Summary of characteristics of two versions of PBL unit used in biotechnology course.

Preliminary Version	Final Version
• Text-based PBL problem	• Text-based PBL problem
Student Assessment	*Student Assessment*
• Guiding assignments (all done in groups) o Defining the Issues o Gathering Information o Solving the Problem	• Guiding assignments o Defining the Issues (group) o Genetic Diseases (individual) o Genetic Testing (group) o Solving the Problem (group)
• Exams (all completed individually; all "closed book") o Pre-unit exam o Post-unit exam	• Exam (completed individually) o Post-unit exam ("closed book") o "Open book" section
Student Evaluations of Unit	*Student Evaluations of Unit*
• How did we accomplish the student learning objectives? (6 questions)	• How did we accomplish the student learning objectives? (6 questions)
• We would like you to rate the effectiveness of the assignments in this component. (3 questions)	• We would like you to rate the effectiveness of the assignments in this component. (4 questions)
• What did you like best about this unit? (anecdotal)	• What did you like best about this unit? (anecdotal)
• What did you like least about this unit? (anecdotal)	• What did you like least about this unit? (anecdotal)
• Other comments about this unit? (anecdotal)	• Other comments about this unit? (anecdotal)

Evaluation

The preliminary version of the PBL unit utilized a pre-unit exam to test student knowledge and understanding of genetic diseases and genetic diagnosis technology before beginning the PBL unit. Students who completed the exam received extra credit points equivalent to just under 0.3% of the total points possible for the entire course. When pre-unit exam scores are compared to the scores for the exam administered after the PBL unit (which was a required exam equivalent to 12% of the total points possible for the entire course), a measure of the increase of student factual knowledge can be determined. This comparison was conducted using Student's *t* test (Steel and Torrie, 1960). The average scores on the pre-unit exam (47.0% ± 19.2; n = 20) and the post-unit exam (79.7% ± 18.2; n = 20) were significantly different ($P = 3 \times 10^{-6}$), indicating a significant increase in factual knowledge.

Students who completed the final version of the PBL unit had lower exam scores than those who had completed a unit covering the same material using a lecture-based instructor-centered approach, based on a very similar multiple-choice-and-essay post-unit exam (P = 0.016; see Table 3 for results). The lower exam scores for the PBL students represented a difference of one half of a letter grade for the exam. It is possible that the students that completed the lecture-based approach were more proficient overall due to previous exposure to biotechnology theory and laboratory work, so overall grades for the entire course were compared between these two groups. No significant differences in overall grades were found ($P = 0.620$; see Table 3).

Assignment scores are summarized in Table 3. The lower n values for the "Genetic Testing" and "Solving the Problem" assignments represent each cooperative learning group being treated as an experimental unit (the "Genetic Diseases" assignment and the exams were completed individually). Based on the grading criteria discussed previously, it is reasonable to assume that, despite their subjective nature, the learning objectives of the unit were fulfilled, with excellent consideration demonstrated by student groups in general in

TABLE 3. Scores for post-unit exam, overall grade for course, and assignments used in PBL format for genetic diagnosis unit compared to scores using lecture-based format for genetic diagnosis unit. All scores are based on a maximum score = 100. Comparisons analyzed using 2-tailed Student's *t* test. N.A. = assignment not used in lecture-based format, so comparison cannot be made.

[a] = Assignment completed individually.

[b] = Assignment completed in cooperative learning groups of 2-3 to 3-4 students.

*** = statistically significant ($P < 0.05$).**

Assignment	Score using PBL unit (final version) ± SD (n)	Score using lecture-based format ± SD (n)	*P*
Post-unit Exam[a]*	80.2 ± 14.8 (227)	84.9 ± 12.1 (53)	0.016*
Overall Grade for Course[a]	84.6 ± 10.7 (227)	85.5 ± 12.6 (54)	0.620
Genetic Diseases[a]	91.3 ± 8.1 (249)	N.A.	N.A.
Genetic Testing[b]	85.5 ± 11.8 (96)	N.A.	N.A.
Solving the Problem[b]	89.7 ± 9.1 (99)	N.A.	N.A.

consideration of Robert's options and the impact each has on their stakeholder. Assignment scores for "Defining the Issues" were not statistically analyzed due to different grading criteria being adopted for this assignment as the study progressed.

In any learning situation, student attitudes greatly impact the degree to which learning can occur (Henderleiter and Pringle, 1999). Student attitudes were determined using their responses to questions posed on the end-of-semester student evaluations concerning the PBL unit. These questions are listed in Appendix C. Results for the questions asking about the learning objectives and the assignments themselves are summarized in Table 4. In anecdotal comments about what students liked most and least about the PBL unit, students indicated that they appreciated the independent research (when the division of labor with their groupmates was successful), exploring the World Wide Web, learning about Huntington disease and other genetic diseases and communicating with other students about the problem. The cooperative learning aspect of the PBL offered students experience in time management, schedule coordination, and division of labor. However, some students expressed concerns about scheduling difficulties for synchronous electronic meetings with their cooperative groups, and the technical difficulties inherent in an on-line setting (such as Internet lag, computer crashes, or bandwidth or browser problems). In addition, group activities decrease some of the temporal and geographic flexibility advantages that asynchronous on-line courses offer.

TABLE 4. Student evaluation ratings in response to the problem-based learning unit in an on-line biotechnology class. Questions are listed in Appendix C. Ratings are based on a scale of 1 (excellent) to 5 (poor).

	Rating Average ± SE	n
How well did we accomplish the following learning objectives:		
1. Understand the nature and mode of inheritance of genetic diseases	1.77 ± 0.70	166
2. Gain an appreciation of the human cost of genetic diseases	1.63 ± 0.67	166
3. Understand the principles and technologies used in genetic testing	1.75 ± 0.73	165
4. Gain an appreciation of ethical, legal, and social issues associated with genetic testing	1.75 ± 0.80	166
5. Develop problem solving skills	2.17 ± 0.88	166
6. Learn how to find and process information in Web-based databases	1.95 ± 0.96	38
We would like you to rate the effectiveness of the assignments in this component.		
7. Defining the issues	2.15 ± 0.91	166
8. Genetic Diseases	1.86 ± 0.75	166
9. Genetic Testing	2.02 ± 0.82	166
10. Solving the problem	2.24 ± 0.93	164

Discussion

A major difference between PBL in a traditional face-to-face learning environment and in an on-line learning environment is the way in which group members interact with each other. In traditional PBL groups typically meet face-to-face in or outside of class time. In the online environment all meetings take place electronically. These meetings may occur synchronously using the telephone, text-based chat or audio/video conferencing or asynchronously using discussion forums or email. There are strengths and weaknesses to each of these approaches.

Synchronous communication technology provides for spontaneity and give-and-take between group members with immediate feedback. A problem with this approach is the difficulty of scheduling synchronous meetings. This is especially true for non-traditional students. Another problem with synchronous communication is the clunkiness of text-based chat. Problems here include typing abilities (especially speed) and the ability to decipher multiple simultaneous threads of conversation. Audio or video conferencing is a superior approach for synchronous communication, but it is not applicable in our situation because we have chosen to restrict the course to low bandwidth technologies (*i.e.* phone/modem) in order to make the course as widely accessible as possible.

Asynchronous interaction provides more time for the individual research required for a student to fulfill his or her role in the group, and also stimulates reflection on the relevant issues the group is discussing. Asynchronous interaction, however, often inhibits spontaneous development of ideas. A student may also make significant progress down the "wrong path" through research before his or her teammates can correct an improper understanding of that student's role in the group for that particular assignment. In addition, asynchronous interaction inhibits the quick allocation of tasks and formation of schedules to get problem-solving activities completed (Garrison and Anderson, 2003).

When the PBL unit was first included in this course, student interaction was generally evenly balanced between asynchronous communication (discussion forums) and synchronous communication (chat room, telephone). As the semesters passed, the use of the chat rooms within the course architecture decreased steadily, while the use of the asynchronous discussion forums increased steadily. This was due in part because we promoted the use of asynchronous technologies by establishing private discussion areas for each group and by encouraging them to meet asynchronously in our initial instructions. We did this so that we could more effectively monitor group interactions. Additionally we have noted anecdotally that, while the proportion of non-traditional to traditional students has remained relatively constant, it now seems that nearly all of our traditional students are working their way through college, as well as non-traditional students. It is thus much harder to schedule synchronous meeting times that agree with the schedules of everybody in the cooperative group. With the widespread advent of e-mail in the late 1990s and early 2000s, students are also much more comfortable with asynchronous communication.

Another difference between distance PBL and face-to-face PBL is the role of the instructor. In PBL the instructor serves as a facilitator who gives feedback, challenges students' understanding of concepts without dominating the group, monitors group dynamics, manages conflicts, knows when and when not to intervene, and empowers students (Mierson, 1998). The role of the instructor as facilitator is more difficult and time-consuming in a distance-education PBL setting than in a face-to-face PBL setting, because the instructor must rely on student self-reporting to identify dysfunctional groups (especially if the group is communicating mostly by private means such as e-mail or chat rooms), or must monitor the group's discussion forum. Sometimes students must be prodded by the instructor to report on their own group dynamics. In our study, several assignments (such as "Defining the Issues") had a small point value given to discussions about their own group dynamics, whether students were equally sharing the division of labor and writing duties with their peers, and so forth.

Another consideration that is especially important in distance education is that of student motivation. Wankat and Oreovicz (1991) identify two forms of motivation, intrinsic (internal pleasure from the intellectual challenge of learning, social interaction, and so forth), and external (grading, encouragement from the instructor, *etc.*). An on-line distance education requires a great deal more intrinsic motivation than a traditional face-to-face course. Rather than having a set-aside time for students to focus exclusively on their learning by going to class, the learning experience is brought to the student's home where it must compete against family obligations, social interruptions, housework, and entertainment. Many students report motivation as a prime difficulty in their evaluations at the end of the semester. The main extrinsic motivation (grading) leads to procrastination followed by cramming, but in distance-education PBL, where students must schedule working on the problem around the schedules of their groupmates, procrastination is not possible without leading to an unequal division of labor (and indeed, procrastination by one member of a group often turns out to be the root cause of many dysfunctional groups). Assignments (extrinsic motivation) must be made due at periodic intervals (we have assignments due at one-week intervals through the 5-week PBL unit) to maintain that extrinsic motivation, which helps support students' intrinsic motivations, and to help prevent procrastination.

A major goal of the PBL unit was to promote higher-order learning (application, analysis, synthesis, and evaluation in the taxonomy of Bloom *et al.* [1956]). The assignments for the PBL unit were designed to evaluate higher-order learning of the human cost and ELSI of genetic diseases and genetic testing. Despite the necessarily subjective nature of the grading process, the reports by the student groups indicate a high level of comprehension of research ("Genetic Diseases"), analysis of relevant issues ("Defining the Issues"), synthesis of ideas in response to a novel situation ("Genetic Testing"), and application and evaluation of resulting principles to the central core question ("Solving the Problem") within the group. The students integrated their learning of material from this course with their individual background and experiences, fusing their ideas to a common consensus within the student groups. This is consistent with Wright *et al.* (1998), who found when dealing with student-centered cooperative active learning that differences in perceived student competence and "student maturity" are correlated with the authentic development of higher-level thinking skills. Another study found that medical students who completed PBL-intensive medical training scored significantly higher than their colleagues who had experienced a mostly-lectured-based curriculum in five areas relating to humanism and social learning, were much more likely to have pursued careers in primary care or psychiatry (as opposed to, for example, surgery or research), and were more likely to believe that their training continued to influence their thinking (Peters *et al.*, 2000). This indicates a greater understanding of the ELSI and human issues through PBL.

What is the impact of PBL on lower-level learning (knowledge and comprehension of factual information)? Does the process of knowledge construction inherent in PBL compromise the acquisition of factual knowledge that is central to science? We addressed this question using exams which measured students' knowledge and comprehension of the basic factual information about genetic diseases and genetic testing. Comparison of pre-module and post-module exam scores indicates that significant factual knowledge is acquired through the PBL format, just as it is in a lecture-based format. However, the post-exam scores for the PBL format were a half grade lower than the post-exam scores when the material was taught using conventional pedagogy. This effect was specific for the PBL unit and was not seen when comparing overall course grade. This suggests that low-level learning may be somewhat compromised using the PBL approach. A note of caution here is that the pre-PBL sample size was relatively small (53 students) and may not be representative.

Why might students score lower on exams testing low-level knowledge and comprehension with the PBL format? Wankat and Oreovicz (1991) propose that learning takes place when a student is presented with information in such a way as to cause disequilibrium. Failure to achieve this disequilibrium may cause a student to feel complacent, and there is no motivation to learn. A student in a state of disequilibrium feels a need to ease his or her intellectual discomfort, and is thus motivated to do something. In other words, in order to learn, students must first understand what they *don't* know (Bransford and Schwartz, 1998). In the process of learning, a student constructs an intellectual scaffolding with supporting concepts that allows him or her to return to equilibrium.

In this study, the students generated their own disequilibrium by completing the "Defining the Issues" assignment, where they acknowledged the information Robert would need to accumulate in order to make an informed decision. Not only would they need to learn much more about the human issues and ELSI surrounding Robert's dilemma, but they would also need to learn much more about the characteristics of genetic diseases and the techniques used in genetic testing. The instructor is responsible for facilitating student access to the information available that will allow the student to begin to construct an intellectual framework; however, the instructor should be careful not to provide too little support (which makes the student feel lost) or too much support (which gives the student no reason to actively participate in his or her own learning) (Erlendsson, 2001). This is more difficult in an on-line class where an instructor does not have face-to-face contact with students, and more difficult in a PBL setting where students are searching to develop their answers largely on their own. Intimidation by the immensity and complexity of the electronic Internet may also be a factor (Jensen *et al.*, 2002). It is possible in our case that the PBL format may be so alien to students who are veterans of a more traditional format that they struggle in an environment where they, rather than their instructor, directs their learning (Cruickshank and Olander, 2002). PBL requires much more motivation on the student's part, as well as more work outside of class (Herreid, 2000). Time constraints may play another factor. While completing the unit, students are focused on the immediate goal of completing the assignments, which are geared to higher-order learning. However, if the development of higher-order understanding by the students is a goal, then assessment should be in the form of problems and opportunities that demonstrate the complexity of the student's thinking process (Wright *et al.*, 1998). Performance on a traditional multiple-choice exam reflects only low-level command of the subject matter, not the high-level understanding that is the focus of PBL. However, the literature indicates no differences in gains of student understanding of factual material through PBL compared to a traditional lecture-based and instructor-centered setting (Dyke *et al.*, 2001).

In evaluations of this unit, students appreciated many of the advantages of working together with their teammates to develop answers to the problems presented, such as "being able to bounce ideas off of" their teammates. PBL also has the advantage of reducing the sense of motivation-reducing isolation that pervades much of distance education. Students did take special notice of inherent cooperative learning disadvantages, such as problems in coordinating schedules, that are also present in real-world teamwork. There are also disadvantages common to all on-line ventures (technical problems such as Internet lag, computer crashes, and other software or hardware problems), and disadvantages unique to PBL and/or cooperative learning in an on-line setting (decreases in temporal and geographic flexibility; differences in feedback, compromise ability, and timeliness between students within a group). These difficulties have been noted by other researchers, who suggest that improvements in the support network (*i.e.* computer software) might help students better manage the division of labor, scheduling, and management of documents chronicling the development of their thoughts (Garrison and Anderson, 2003).

Conclusion

PBL has been effectively used to promote higher order learning in many disciplines in a face-to-face environment. We wanted to know whether this pedagogy would also be effective in an on-line environment. Our results indicate that higher-order learning and construction of understanding of the science and ELSI of genetic testing is taking place through the use of this PBL environment. Student reaction to the course was generally positive, but with some reservations about the effectiveness of group work in an on-line class.

Is virtual PBL a viable pedagogy in other on-line courses? There is a substantial body of research showing that there is no significant difference in learning between the Internet-based and face-to-face educational environments (reviewed in Russell, 2001). Is the use of PBL in the on-line environment any different? There are obvious differences between face-to-face PBL and on-line PBL with regards to cooperative communication (asynchronous *vs.* synchronous), scheduling, interpersonal relationships, student motivation, timeliness, and technical problems with hardware, software, or infrastructure. However, we feel with student performance on this unit that the advantages of the cooperative PBL format, such as increased higher-order learning and deeper student understanding, balance the disadvantages experienced by certain students and student groups. It is our belief that PBL is a valid and valuable means of increasing student learning in any on-line class where higher-order learning is desirable.

We found that there was a small but statistically significant difference in lower level learning as measured by an exam at the end of the unit. It is not clear whether this is an inherent feature of PBL in an on-line environment or whether it is simply a feature of this particular case. There is an extensive literature showing that there is no significant difference between lecture-based student performance and PBL student performance on standardized exams (Wright *et al.*, 1998; Dyke *et al.*, 2001; Cruickshank and Olander, 2002; Michel *et al.*, 2002). However, standardized exams are specifically designed to test knowledge of the type that is easily conveyed through a lecture-based format. Wright *et al.* (1998) and Michel *et al.* (2002) suggest that the strength of PBL is not measured by student performance on multiple-choice exams, but by demonstration of higher-order learning through guided authentic learning activities.

A factor that may impact student learning is the sense of connection of lack thereof to the central problem that the students face. The PBL unit in this study is text-based but could be re-contextualized to be more integrated, transforming the on-line delivery of this PBL unit from being oriented towards a technical imperative to being oriented towards a pedagogical imperative (Oliver and Harrington, 2000). In other words, the PBL unit could be made more immersive for students by using seamless access to resource material such as streaming multimedia that takes them intimately into Robert's world. Immersion transforms the PBL situations, such as Robert's dilemma, from an abstraction into a context "within which a particular situation is perceived, interpreted, and judged" (Broudy, 1976). Work is in progress to explore the effects of adopting an immersive multimedia-rich environment on fulfillment of the learning objectives of this PBL unit.

CHAPTER 5

DESIGN AND ASSESSMENT OF IMMERSIVE PROBLEM-BASED LEARNING IN AN ON-LINE BIOTECHNOLOGY COURSE

A paper to be submitted to
The International Review of Research in Open and Distance Learning

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Abstract

Problem-based learning (PBL) is the use of a "real world" situation as a context for learning. We combined PBL pedagogy with a rich multimedia environment of streaming video interviews, physical artifacts, and links to articles and databases to create an immersive PBL environment called "Robert's World". In "Robert's World", students determine whether a man should undergo a pre-symptomatic DNA test for an untreatable, incurable, fatal genetic disease for which he has a family history. Design and implementation of the immersive environment and of the PBL pedagogy, which drives learning in this environment, is discussed. Evaluation indicates that the immersive PBL environment engaged student interest and stimulated higher-order learning. However, student performance on an exam testing acquisition of factual knowledge indicated that higher-order learning was not being translated into lower-order learning. Possible reasons are explored. We conclude that on-line immersive PBL is a valid pedagogical tool wherever higher-order learning is desirable.

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Introduction

Problem-based learning (PBL) is defined as the use of a "real world" problem or situation as a context for learning (summarized in Maudsley, 1999; Michel *et al.*, 2002). The purpose of PBL is to encourage student development of critical thinking skills, a high professional competency, problem-solving abilities, knowledge acquisition, the ability to work productively as a team member and make decisions in unfamiliar situations, and the acquisition of skills that support self-directed life-long learning, self-evaluation, and adaptation to change (Engel, 1991; Albanese and Mitchell, 1993; Ryan and Quinn, 1994). In PBL, this is achieved by using situations or problems presented in class that resemble reality. In many cases, the realistic problems used in PBL studies may not have a right or wrong answer. Instead, PBL stimulates the construction of a conceptual network of knowledge in students, which can then be applied in a wide range of practical settings (Creedy and Hand, 1994; Cruickshank and Olander, 2002). In PBL, the focus is on the *process*, not the *product* (Patel *et al.*, 1991; Margetson, 1994; Shannon and Brine, 1994). PBL usually presumes that student understanding comes from student interactions with the environment (both inside and outside the classroom), that cognitive conflict stimulates learning (expanded upon by Willingham, 2004), and that knowledge evolves through social discourse and evaluation of the viability of individual understandings. These assumptions are consistent to constructivist philosophy (Savery and Duffy, 1995). PBL instructors, as a result, often become facilitators, coaches, and mentors, rather than the positivist stereotypical "fount of knowledge" (Collins *et al.*, 1989; Mullins, 1994; Russell *et al.*, 1994; Mierson, 1998).

PBL is typically conducted using heterogeneous cooperative learning groups (Anderson and Henley, 1994; Cuseo, 1996; White, 1996) in a face-to-face setting. Far fewer studies have been conducted about the use of PBL in the electronic-based distance-education "virtual classroom" (Cheaney and Ingebritsen, 2005). While higher education has been quick to adopt the Internet for course delivery, the focus thus far has been largely on technical imperatives such as expediency and ease of transferring course material to the Internet (Maddux, 2002; Stevens, 2002). The use of traditional assessment tools and the treatment of the subject material as a static entity that can be “downloaded” to students as if they were computers draws attention away from pedagogical research into student-centered learning environments and limits instructors’ creativity in designing educational innovation (Jonassen, 2000; Maddux, 2002).

The versatility of the Internet, however, combined with its cost-effectiveness in overcoming the geographic limitations of the traditional university, presents educators with the potential to produce pedagogically- and scientifically-sound authentic learning experiences. These integrated approaches may revolutionize, supplement, complement, and enrich the most fundamental aspects of science education, both at a distance and in the traditional college setting (Oliver and Harrington, 2000).

Students often miss important ideas in their classes because their knowledge is not oriented towards recognition of meaningful patterns and not as flexible as that of experts (deGroot, 1965). The introduction of a PBL environment that immerses students in a particular situation provides a context in which initially abstract concepts are transformed into a more nuanced form of understanding (Engeström, 1999). The net result is that students are forced to construct an understanding that combines elements of both pre-existing relevant knowledge and new information learned in class. In working through the problem presented by the PBL situation, a student’s understanding develops into the meaningful patterns and principles that govern the topic (National Research Council, 2000). In short, students begin to develop "adaptive expertise", the type of thinking that distinguishes "highly competent" from "merely skilled" practitioners (Miller, 1978; Hatano and Inagaki, 1986).

In an immersive environment, students deal with the exigencies at hand, recognizing what they don't understand, the necessary first step of learning (Bransford and Schwartz, 1998). This recognition process may be uncomfortable for students, but it forces them to draw on their previous experiences both from classes and from extracurricular experiences as they struggle to make sense of a new situation. The deficiencies in the student's understanding needed to come to a conclusion are apparent and ready to be filled by the expertise of the instructor or other experts whose understanding can be tapped. For example, many students go through introductory biology courses that introduce the molecular and physiological mechanisms of genetic diseases such as cystic fibrosis and Huntington disease. However, it is one thing to know facts about these diseases in the abstract, but quite another thing to role-play a genetic counselor, family member, employer, or insurer dealing with an individual with a family history of one of these diseases. In this case, the necessary understanding of the molecular and physiological properties of the disease are joined by an equally necessary attention to legal concerns, ethical and professional practices, social and interpersonal discourses, and even a philosophical introspection on the nature of death (or at least disability). The context of the problem simply provides a foundation upon which the student can perceive, interpret, and judge the relevant issues (Broudy, 1976). This perception, interpretation, and judging involves the critical attention to detail and involvement that is such an important determiner of learning (Langer, 1997).

Historians of distance learning often divide the evolution of distance education into a first generation (behaviorist lecture-based drill and memorization), second generation (audiovisual presentations via TV telecourses), and third generation (highly-integrated content, assignments, and projects combined with copious amounts of communication, both synchronous and asynchronous, via computer technology) (Garrison, 1985; Nipper, 1989). Taylor (1995, 2001), however, has articulated a fourth generation (high amounts of content retrieval, full utilization of the interactive capacity of computer-mediated communication, and use of locally distributed processing) and a fifth generation which he refers to as the "intelligent, flexible learning model" (integrating portals to resources, artificial intelligence to exploit the "semantic web", and "intelligent agents" that are long-lived, semi-autonomous, proactive, and adaptive, capable of monitoring resources and making decisions). While educational philosophers argue whether or not these fourth and fifth generations are actually just continued evolution of the third generation, what these additional generations recognize is the flexibility and potential of the Internet. As Mitchel Resnick observed (1996):

> The Internet acts as a type of Rorschach test for educational philosophy. When some people look at the Internet, they see it as a new way to deliver instruction. When other people look at it, they see a huge database for students to explore. When I look at the Internet, I see a new medium for construction, a new opportunity for students to discuss, share, and collaborate on constructions.

While earlier studies examined the use of a text-based PBL format in a distance learning setting (Cheaney and Ingebritsen, 2005), the networking power of the Internet makes possible a much richer immersive multimedia environment. Instead of just reading about an individual with a problem that the students must make a decision about, students can watch him or her in an interview, at work, and at home, leaf through his or her personal papers (if the individual is fictional), and even talk to the individual. Instead of just reading about the technology that could be used to help make a decision and reading abstract theories about ethical matters involved in such a decision, students can role-play the role of experts themselves, and also listen to and communicate with real-life experts both inside and outside the university. Students can learn how to transfer their learning to other case studies involving superficially-similar but quite different situations, which causes their learning to be modified into more abstract general principles instead of rigorous methodology on how to solve such a problem only in the original context (Gick and Holyoak, 1983). Finally, an immersive PBL environment can help students develop metacognition. Metacognition, which is often defined as "learning how to learn", is the ability to monitor's one own learning of material. Metacognition is a defining characteristic of adaptive expertise and helps to generate an ability to transfer learning from one situation to another by focusing on the generalizable features of critical decisions and the strategic levels of problem-solving, while limiting specific solutions to the problem at hand (White and Frederickson, 1998; National Research Council, 2000). Teaching students how to learn is also an important part of generating life-long learning (Erlendsson, 2001).

Design of the Problem-Based Learning Unit – "Robert's World"

An immersive PBL unit has been used in an on-line undergraduate/graduate course entitled "Biotechnology in Agriculture, Food and Human Health". This is a survey course that covers technology and applications of biotechnology as well as ethical, legal and social issues (ELSI) associated with its use. The course is supported by WebCT architecture and consists of on-line audiovisual lectures and reading assignments from various resources, authentic learning activities (60% of the grade), and on-line exams (40% of the grade). Students can communicate with the instructor and with each other through WebCT's internal e-mail, discussion forum, and both private and public chat rooms. The student population has been largely a mix of traditional undergraduate and graduate students majoring in molecular biology or genetics or working in an on-campus lab, professionals working for seed or other biotechnology companies (often these students have a business rather than a science background), and farmers who want to learn more about the seeds they are planting and harvesting, but students from all walks of life have also been represented. The number of students typically ranges from 15–30 students per semester, with a typical 25–30% drop rate between the beginning and end of the semester, mostly about one month into the semester (right before the beginning of the PBL unit). More details about the course have been reported by Cheaney and Ingebritsen (2005).

The immersive PBL unit, titled "Robert's World", deals with pre-symptomatic diagnoses of genetic diseases. This unit occupies a 5-week span in the middle of the semester. At the beginning of the PBL unit, students are asked to think about Robert, a fictional 33-year-old airline pilot whose mother died of an incurable fatal neurological genetic disease called Huntington disease (HD). As students will learn later in the PBL unit, Huntington disease is caused by a defect in a gene (*HD*) inherited in a dominant fashion (which means that inheritance of just one form of the abnormal gene usually leads to the development of HD). Thus, assuming there is no history of HD in his father's side of the family, Robert has a 50% chance of having inherited the abnormal form of *HD*. Symptoms are classically manifested as progressive involuntary spasms and dementia. A review of more technical information about HD can be obtained from the National Center for Biotechnology Information's Internet site (http://www.ncbi.nlm.nih.gov/entrez/dispomim.cgi?id=143100). Robert's mother began exhibiting HD symptoms at the age of 34, and survived for 16 years before succumbing at 50. Despite the lack of a treatment or cure for HD, there is a pre-symptomatic DNA test to determine the nature of a patient's *HD* gene. A positive result usually means the patient can look forward to an early and unpleasant death, and currently there is nothing he or she can do about it. The ultimate student objective of the class activity is to make a decision about whether Robert should undergo pre-symptomatic DNA testing for HD. Cooperative student groups role-play various stakeholders in Robert's decision (such as Robert himself, his wife, his 4-year-old daughter, his employer, or his insurance company) and decide over the course of the unit through meetings, assignments, and research, whether to advise the man to take the test or not. A PBL unit featuring a man facing the prospect of a DNA test for an incurable genetic disease has been used in this course previously in a text-based format (Cheaney and Ingebritsen, 2005). However, in a linear text-based format, the problem seemed abstract and remote, with the air of a sterile academic exercise. Transformation of the PBL unit into an integrated, multi-dimensional, immersive environment transformed the PBL situation from an abstraction into a more realistic context "within which a particular situation is perceived, interpreted, and judged" (Broudy, 1976). The focus of the PBL unit was shifted from the technical expediency of "getting the class on the Internet" towards a pedagogical imperative of experimenting with new learning techniques in hopes of improving the students' educational experience (Oliver and Harrington, 2000).

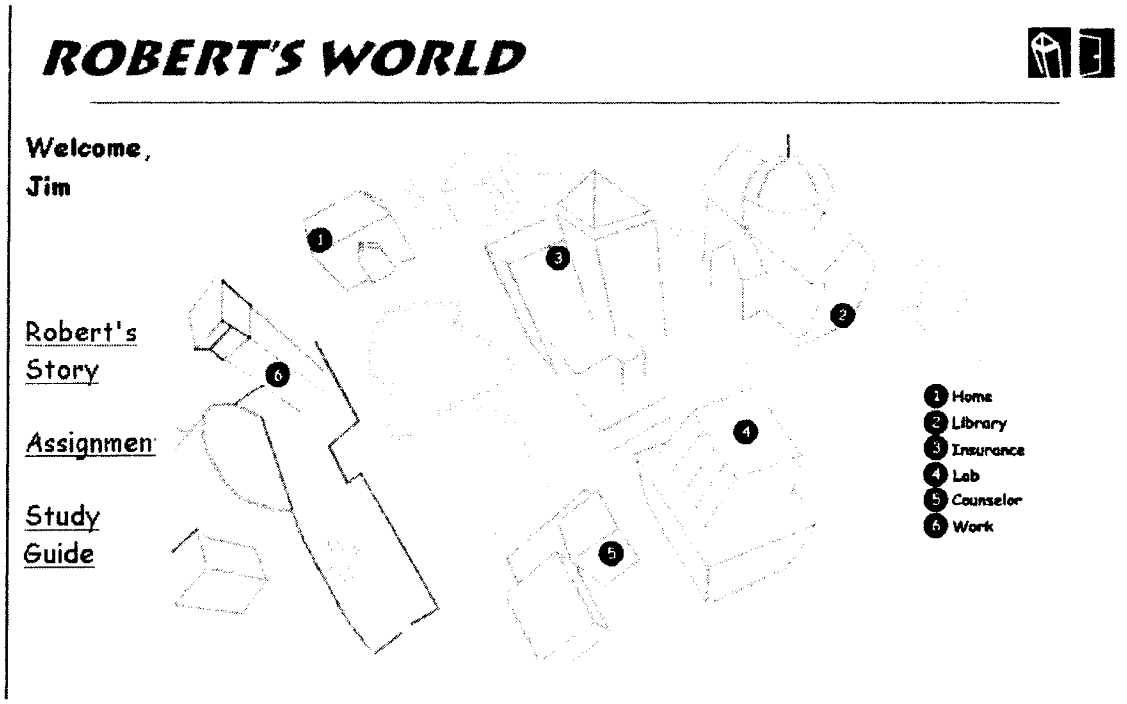

FIGURE 7. Layout of Robert's World (http://weblearning.engl.iastate.edu/RobertsWorld/; username="guest"; password="guest"). From this hub, students can link to various facets of Robert's life (home, insurer, genetic testing lab, genetic counselor's office, and work) and a central information hub (library) to gather information needed to provide Robert with advice on whether or not to seek a pre-symptomatic DNA test for Huntington disease. ***Note:*** **This figure is identical to Figure 6.**

Robert's World (http://weblearning.engl.iastate.edu/RobertsWorld/; username="guest"; password="guest") consists of a central hub with a user interface that looks like a map of a city (Figure 7). From this hub students can navigate back and forth to and from several locations corresponding to various aspects of Robert's life (*i.e.* home, work, *etc.*). The videos, assignments, and physical artifacts (such as medical forms, insurance files, and laboratory records) can be accessed from these several sites. Videos include interviews with actors playing the parts of the major characters, and interviews with real-life experts in the fields of bioethics, genetic counseling, genetic testing, and insurance. In addition, external links provide students with access to extensive amounts of information, especially

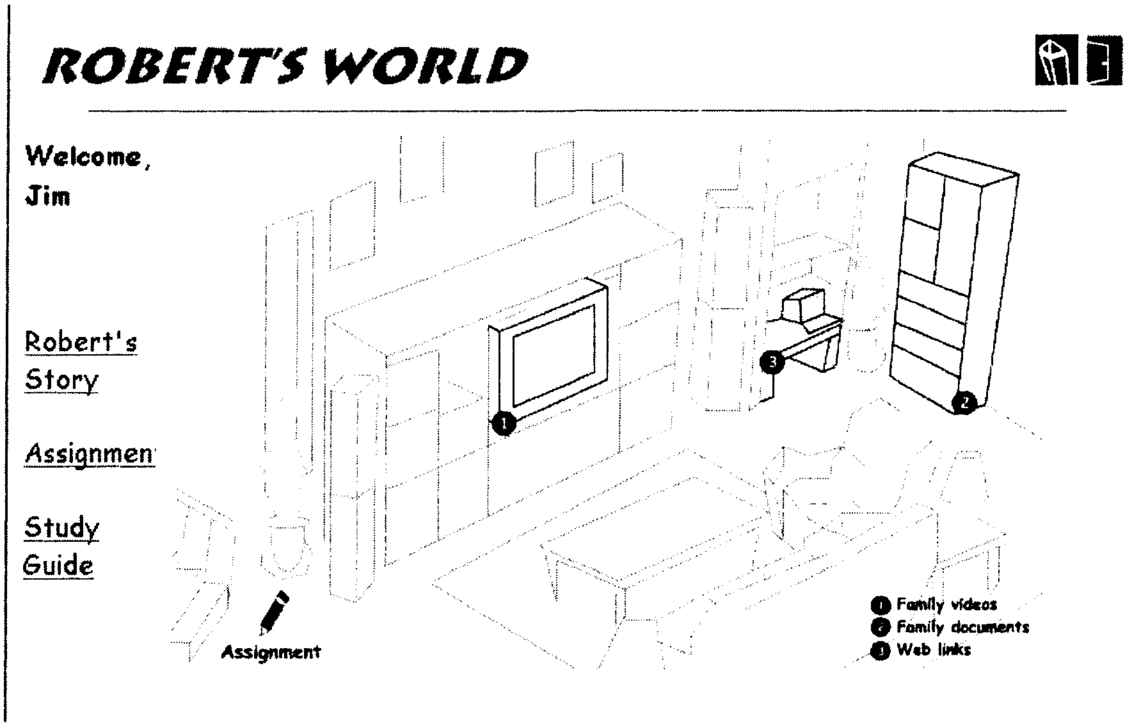

FIGURE 8. Layout of Robert's home in Robert's World. From this hub, students can link to videos of interviews with actors playing the part of Robert (Figure 9) and Angela, his wife (both located at the TV set). They can also link to the family financial records (the bookshelf) and the human impact of Huntington disease (the computer terminal). The pencil at lower left links to the "Describing the Disease" and "Making a Decision" assignments (see text).

medical/genetic information, and legal information on what federal and state laws say (and do not say) about asymptomatic diagnoses of genetic diseases. The different locations within Robert's life that the students can access are as follows:

1) Home. From Robert's home (Figure 8), students can view interviews with actors playing the parts of Robert (Figure 9) and his wife. They also have access to family documents (such as financial obligations) that can give students a better idea of what Robert's resources are (an essential part of helping Robert make a decision, if the student group is playing the part of Robert, his wife, or his daughter). The computer desk in Figure 8

FIGURE 9. Robert discusses his feelings about Huntington disease and his mother's battle with the disease.

leads to a set of links that introduce students to HD and its social and human impact. The pencil at the bottom left-hand corner leads to the last 2 assignments of the unit ("Describing the Disease" and "Making a Decision", both described later).

2) Library. The library is a storehouse of links to on-line audiovisual lectures from earlier in the semester that provides a review to students of the biotechnology methods covered earlier. The library also provides links to all the articles and sites provided elsewhere (redundant to the other sites in Robert's World) for quick reference from one key hub. Students can also access interviews with genetic counseling, genetic testing, and bioethics experts.

3) Insurance Company. The skyscraper downtown represents the headquarters of a local insurance company. From this site, students can access interviews with an insurance professional discussing Robert's case. They also have access to articles and links discussing legal and financial regulations concerns regarding presymptomatic DNA testing, including the Health Insurance Portability and Accountability Act of 1996 (HIPAA), the proposed Genetic Information Non-Discrimination Act, the Americans with Disabilities Act, and Title VII of the Civil Rights Act of 1964.

4) Genetic Testing Lab. At the genetic testing lab (Figure 10) students can take a virtual tour of a real genetic testing lab (Figure 11). They go through the entire process, from drawing the patient's blood all the way to disposal of the sample after DNA analysis is complete. Through various links, both local and on the Internet, students can learn how to interpret results from a presymptomatic DNA test for HD, and can also learn how exactly the

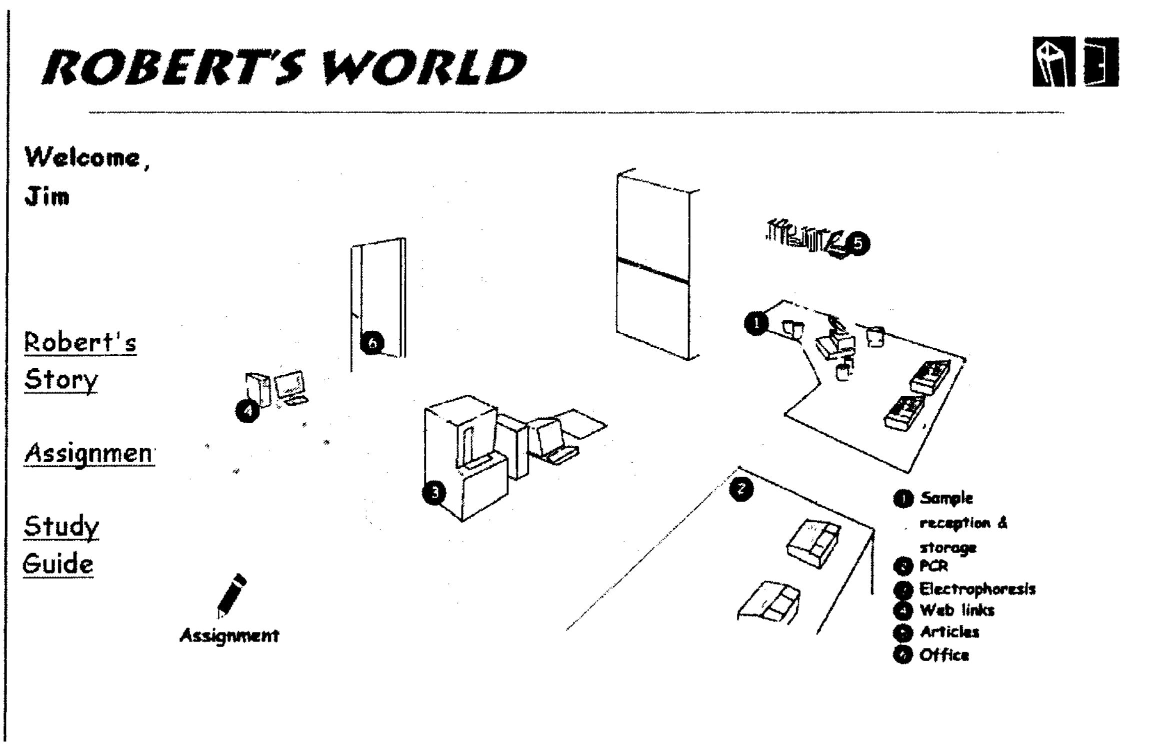

FIGURE 10. Layout of Genetic Testing Lab in Robert's World. From this hub, students can link to a video tour including sample reception and storage (in the far right corner), the polymerase chain reaction necessary to have enough DNA to analyze (on counter at very bottom), and a view of how electrophoresis of DNA samples for analysis occurs (in middle of room). Also included are links to a database listing different types of genetic tests currently conducted (computer monitor at left), articles discussing specifics of Huntington disease testing (books at top right), and an interview with a genetic testing lab manager about miscellaneous procedural information not covered in other parts of the video tour (beyond the door at the upper left).

FIGURE 11. A lab technician with the Molecular Diagnostic Lab at the University of Minnesota Medical Center, Fairview, prepares DNA samples for electrophoresis.

DNA is analyzed and what each data point represents in an HD test. The pencil at the bottom left links to an assignment called "Genetic Testing", which will be described later.

5) **Genetic Counselor's Office.** The genetic counselor's office (Figure 12) features links to interviews with a professional genetic counselor (Figure 13) and two professors of bioethics. They describe the profession of genetic counseling, a profile of the professional community, the training involved, and the entire process of genetic counseling, including psychological, interpersonal, medical, financial, legal and regulatory, ethical, reproductive, and disability issues for both HD and other genetic diseases. The office also provides links to articles and databases providing information about genetic tests, and a sample of informed consent documents involved. The pencil at the bottom left of Figure 12 links to two assignments ("Genetic Diseases" and "Genetic Counseling", both described later).

6) **Work.** Robert's workplace (an airport) features links to sites describing Robert's employer's rights and obligations under federal law. It also provides links to Federal Aviation Administration medical standards and guidelines. As a pilot, Robert is

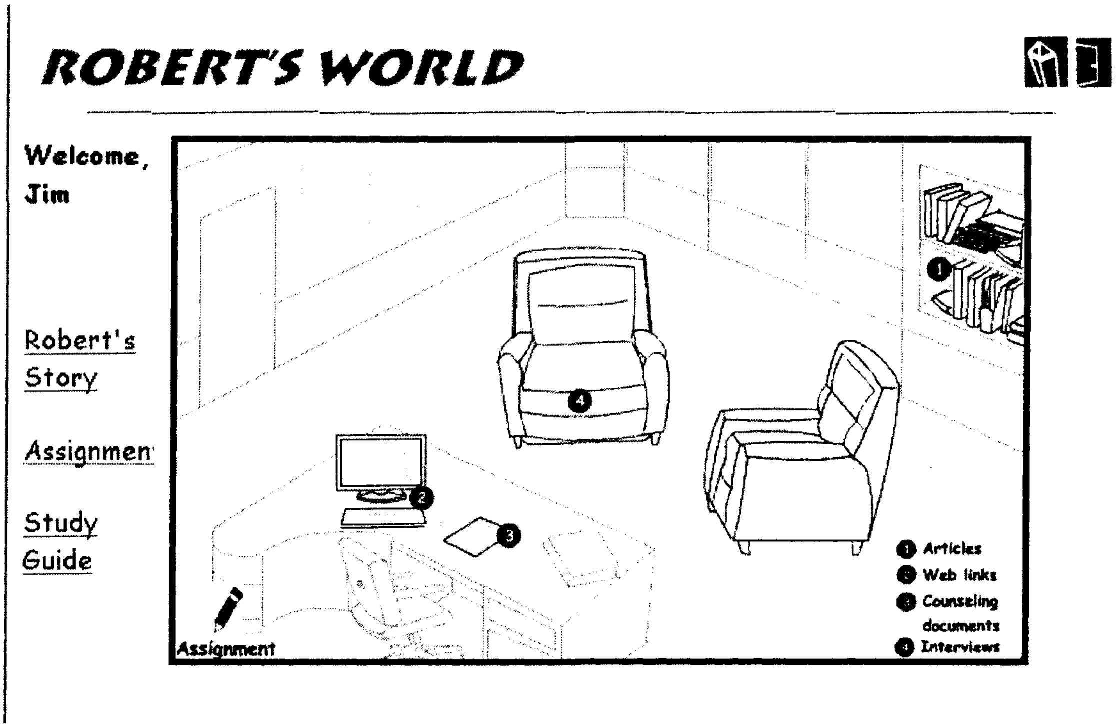

FIGURE 12. Layout of Genetic Counselor's Office in Robert's World. From this hub, students can link to articles discussing specifics of Huntington disease testing (books at top right), links to a database listing different types of genetic tests currently conducted (computer monitor at left), samples of what an informed consent form looks like and what type of questions are asked (form on desk), and interviews with a genetic counselor and two bioethicists about the procedure and concerns regarding genetic counseling, and the ethical concerns Robert and the other stakeholders in his decision will be facing (chairs).

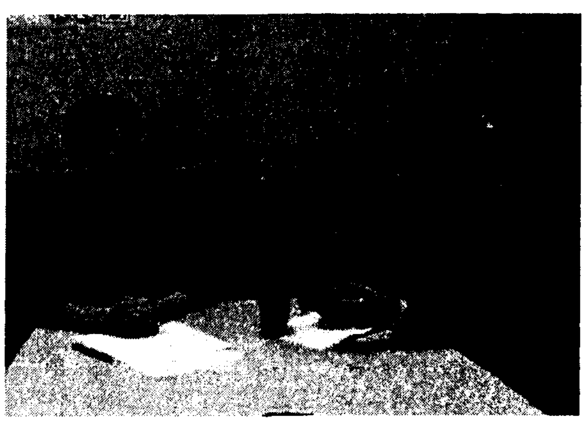

FIGURE 13. Bonnie LeRoy, director of graduate studies in genetic counseling at the University of Minnesota, talks about the profession of genetic counseling and some of the issues that Robert's genetic counselor might encounter. Looking on is Dr. Dianne Bartels, a bioethicist at the University of Minnesota.

regularly entrusted with the lives of passengers who depend on his health and his ability to do his job. The genetic status of employees in sensitive jobs is becoming an increasingly controversial battlefield in the struggle to balance the public good with an individual's right to privacy (American Civil Liberties Union, 2002; Oak Ridge National Laboratory, 2004).

The learning objectives for the PBL problem are as follows:

- Understand the nature and mode of inheritance of genetic diseases
- Gain an appreciation of the human cost of genetic diseases
- Understand the principles and technologies used in genetic testing
- Gain an appreciation of ethical, legal, and social issues associated with genetic testing
- Develop problem-solving skills
- Learn how to find and process information in Web-based databases

Cooperative learning groups provide students with an opportunity to work collaboratively, a situation more similar to "real world" professional situations than the more-traditional educational environment that emphasizes individual work (Resnick, 1987). The cooperative learning groups for the PBL unit were assigned into groups of three to four. Each group provided a mix of students taking the class for undergraduate or graduate credit. Groups were also assigned to provide a geographic mix, to prevent some groups from having an unfair advantage if they decided to meet in person (if all members lived, for example, in the same county), while other groups were limited to electronic teleconferencing means. No attempt was made to separate students by GPA or overall grade in the class.

Research into the pedagogy of Robert's World can begin to answer several concerns that exist about immersive PBL environments. First, does immersive PBL promote higher-order learning? Higher-order learning is defined as analysis of the issues associated with a problem, application of learning in a new situation, synthesis or construction of a new understanding from its parts, and evaluation or judging of understanding against criteria

(Bloom *et al.*, 1956; Cruickshank and Olander, 2002). Second, does immersive PBL promote lower-order learning, such as basic knowledge (recalling facts) and comprehension (or general understanding of the concepts covered)? Finally, what were student reactions and attitudes concerning the immersive PBL environment?

Authentic Learning Activities

Authentic learning activities allow us to both assess student learning and also provide a means to guide student learning directionally (*i.e.* they have somewhere to go within Robert's World, and a reason to go there). However, assessment of authentic learning experiences is a controversial part of the literature surrounding PBL. It is difficult to devise a strictly objective means of assessing student performance in learning material. Assessments of authentic learning experiences must involve problems and provide opportunities where the complexity of the student's thinking process is exhibited (Wright *et al.*, 1998; Garrison and Anderson, 2003). In the PBL unit that we are utilizing, assessment was made through student performance on traditional exams consisting of multiple-choice questions (see Appendix B), the students' presentation of different aspects of the problem through the process of writing papers, their ability to transfer their understanding of HD to a difficult situation involving a quite different genetic disease, and their ability to internalize their understanding of biotechnology methods and ELSI in order to devise a novel genetic test or a new means for Robert to approach his problem and decision.

Before gaining access to Robert's World, students read a text-based introduction to Robert, his family, and his dilemma. Student groups then completed an assignment called

"Defining the Issues". In this assignment, student groups were asked to identify the ELSI involved in Robert's decision and the types of information that will be needed for Robert to make an informed decision. This information might be not only scientific and technical, but also emotional information (such as from his family). Thus, students will be drawing from not only their academic experiences, but also from their experiences outside the university and their own philosophical mindset, thus making their upcoming learning experience more relevant, increasing its effectiveness (Bransford and Schwartz, 1998). Students were encouraged not to conduct research on HD (yet), or to reach a decision (yet) on whether Robert should have the genetic test done. According to the learning taxonomy developed by Bloom *et al.* (1956), students were engaged in analysis of Robert's situation and applying their own previous knowledge and values to some of the concerns he will be facing.

The remaining assignments were embedded within Robert's World. All but one assignment were group assignments, which required extensive student collaboration to reach a consensus on what the group would say when it reported. These assignments are listed below:

- "Genetic Diseases", a group assignment, at the genetic counselor's office
- "Genetic Testing", a group assignment, at the genetic testing lab
- "Genetic Counseling", an individual assignment, at the genetic counselor's office
- "Describing the Disease", a group assignment, at Robert's home
- "Making a Decision", a group assignment, at Robert's home

The first two assignments were carried over from an earlier text-based version of the PBL unit (Cheaney and Ingebritsen, 2005). In the "Genetic Diseases" assignment, student groups answered a set of specific questions (see Table 5) about a genetic disease of their choice from a limited set and the characteristics of its manifestation, and the gene and genetic mutation associated with the genetic disease. In the "Genetic Testing" assignment, student groups designed a novel pre-symptomatic genetic test for a fictional genetic disease, based on their understanding of DNA technologies used for genetic diagnoses.

In the "Genetic Counseling" assignment, individual students role-played the part of a genetic counselor dealing with a quite different disease in a quite different situation from Robert's dilemma with HD. In this assignment, a woman has a family history of early-onset breast cancer in her female relatives and breast cancer in her male relatives. Her gynecologist suspects a genetic predisposition and has referred the woman to a genetic counselor about the possibility of taking a genetic test for the mutant alleles of *BRCA1* and *BRCA2*, two genes which normally code for proteins involved in embryonic development. Unlike HD, however, the mutant alleles for *BRCA1* and *BRCA2* do not automatically condemn their owner to a future with breast cancer. They are simply one risk factor among many, and many women with the mutant *BRCA1* or *BRCA2* alleles live a natural lifespan with no hint of carcinogenesis. In addition, although a major killer among American women, breast cancer, unlike HD, is not 100% fatal if detected and treated early. To make this dilemma more complicated, this woman also has an identical twin sister who was adamantly opposed to genetic testing on religious grounds. Facing the dilemma of two women with an identical genetic complement but opposing views on the desirability of knowledge about their genes, and the possibility of a mutant gene that might give neither, one, or both a higher risk of a non-automatically-fatal but still devastating genetic disease, students wrote a detailed plan describing what they planned on telling and wanted to discuss with their client at the first genetic counseling session. This exposed the students to more human issues and changes their focus away from HD and towards a more holistic view of the tense relationship between the ability to test for a genetic mutation in general, and the ethical, legal, social, and human issues that inevitably go along with this technological breakthrough. Students had access to extensive video interviews with a genetic counselor and two bioethicists, and external sites that serve as resources for exploring the legal, ethical, and interpersonal issues that surround genetic counseling. The assignment also provided direction to learn more about genetic counseling by exploring this very important part of Robert's World, and to view the videos provided (Figure 13). In this assignment, students were applying what they were learning about genetic testing and the nature of genetic diseases in a novel situation (transferring their knowledge to a new set of conditions), synthesizing a way to explore those issues with their client under the guidelines of the genetic counseling profession, and evaluating the possible decisions that the client might make without prescribing a particular course of action.

In the "Describing the Disease" assignment, student groups role-played the part of Robert and wrote a script answering questions posed by his wife. As Robert, they described the clinical features of HD, information about the gene, the genetic defect and the mode of inheritance of the disease, information about genetic testing for HD, and what positive and negative results for the gene might mean to the two of them and their family. The first-person orientation of this assignment forced students to internalize the human cost that would be felt by Robert's entire family concerning the matter of this genetic heritage. In addition, Robert's wife is a non-scientist, so the students needed to translate all of their technical information into non-technical language. This is a form of transferring knowledge that is somewhat different than what the students experienced in the "Genetic Counseling" assignment. It is one thing to read and understand technical information from scientific sources; it is quite another to understand it well enough to translate it into layperson's language. In one study, middle school students who were required to report scientific findings to older students not involved in the class performed significantly better on conceptually oriented test questions (Yore *et al.*, 1999). As Nobel laureate Peter Debye once remarked, "You don't really understand something until you can explain it to the man on the street" (cited in Styer, 2002). This assignment gave students the opportunity to demonstrate their comprehension of the causes, manifestations, and implications of HD, and to analyze what a family history of HD means to Robert from an internalized point of view.

The climax of the PBL unit is the "Making a Decision" assignment. In this assignment, student groups used a structured decision-making process to decide whether the individual should be tested for the genetic disease. The decision-making process first involved identifying the stakeholders. Groups were then assigned to role-play one of the five principal stakeholders in Robert's dilemma (Robert, his wife, his daughter, his employer, and his insurance company). Role-playing this stakeholder, student groups brainstormed about possible options they might recommend to Robert, considering the effect of various options on their interests and finally choosing the "best" solution that they would recommend to Robert. The students then wrote a report on this decision, focusing on the logical defense and reasoning for their opinion. Students were not graded on their opinions *per se*, but on the persuasiveness and completeness of their arguments. Students applied their knowledge to the final situation and synthesized an appropriate response considering the varied and diverse concerns of the various stakeholders. In justifying their final recommendation, students evaluated the various arguments for and against Robert having the test done and all the variations thereof (such as when Robert should have it done, who should be involved in the decision, and so forth), and argued in defense of their decisions. These arguments reflected their own construction of values based on their research while recognizing those arguments' inherent subjectivity. According to Bloom *et al.* (1956), therefore, the "Making a Decision" assignment can be classified under the application, synthesis, and evaluation domains.

Students also completed a post-PBL-unit multiple-choice exam to test mainly their lower-order understanding of the nature and inheritance of genetic diseases, the technology used in pre-symptomatic diagnoses of genetic diseases, and some of the ethical and legal issues surrounding pre-symptomatic DNA testing. Exam questions were taken from a test bank with several possibilities for each question, to minimize concerns about students talking with their friends about "what's on the test" (always a major concern in mostly-asynchronous courses). All of the exam questions used, possible answers, and correct answers are listed in Appendix B.

Evaluation and Discussion

Does immersive PBL promote higher-order learning? Earlier research with a text-based PBL problem indicated that PBL promotes higher-order learning – application, analysis, synthesis, and evaluation (Cheaney and Ingebritsen, 2005). The assignments associated with Robert's World were designed to evaluate higher-order learning of the human cost and ELSI of genetic diseases and genetic testing. Despite the necessarily subjective nature of the grading process, the reports by the student groups indicate a high level of comprehension of research ("Genetic Diseases" and "Describing the Disease"), analysis of relevant issues in dealing with HD ("Defining the Issues" and "Describing the

Disease"), synthesis of ideas in response to a novel situation ("Genetic Testing" and "Genetic Counseling"), and application and evaluation of resulting principles to the central core questions ("Solving the Problem" and "Genetic Counseling"). Scores from these assignments are summarized in Table 5. Also listed are the scores from the various questions used in the rubric for the "Genetic Diseases" assignment, and the scores for facets of the "Genetic Testing" assignment listed in the rubric, and correlated exam questions (discussed below). Rubric requirements are not included for "Genetic Counseling," "Describing the Disease," or "Making a Decision." For these three assignments, the largest proportion of points went towards students being complete and thorough (*i.e.* did they cover everything?). Other requirements for these three assignments (strength of logic, originality and creativity in tackling ethical issues, *etc.*) were necessarily subjective, and are not reported here.

To complete the assignments, the students integrated their learning of material from this course with their individual background and experiences, fusing their ideas to a common consensus within the student groups, a process called "distributed cognition" (Vye *et al.*, 1997). This is consistent with Wright *et al.* (1998), who found when dealing with student-centered cooperative active learning that differences in perceived student competence and "student maturity" are correlated with the authentic development of higher-level thinking skills. Peters *et al.* (2000) found a greater interest in and understanding of humanist and social issues among medical graduates who had completed a PBL-intensive curriculum.

The PBL unit utilized an exam to test student lower-level understanding of genetic diseases and ELSI following the PBL unit. Questions that were used in this exam, as well as possible answers and correct answers, are listed in Appendix B. Over the course of the 4 semesters in which this immersive PBL unit was used, the average score for such an exam

TABLE 5. Scores for authentic learning assignments used in immersive PBL format for genetic diagnosis. All scores are based on a maximum score = 100.

Note: **Scores for specific questions (and total % possible) will not add up to total overall score (or 100%) because of additional points not reported here, such as clarity and readability.**

Assignment Specific question asked in assignment, from rubric (maximum % of overall total)	Paralleled Question from Exam	Summer 2004 (n)	Fall 2004 (n)	Spring 2005 (n)	Summer 2005 (n)	Weighted Avg. (n)
Gen. Diseases (overall) [a]		84 (5)	86 (5)	83 (4)	87 (5)	85 (19)
What causes the disease? (40%)	10, 11	79	86	88	89	85
How is it inherited? (13%)	1, 2, 3	92	88	75	82	85
How is it treated? (13%)	–	88	80	75	80	81
What's it like to have the disease? (20%)	–	87	83	75	93	85
Genetic Testing (overall) [a]		79 (5)	76 (6) [c]	95 (4)	87 (5)	83 (20)
Principle of test & how performed (67%)	10	78	66	96	86	80
Interpretation of results (20%)	4, 8–9	61	81	90	79	77
Genetic Counseling [b]	7	78 (18)	72 (16)	72 (13)	76 (16)	75 (63)
Describing the Disease [a]	1, 10, 11	91 (5)	87 (5)	89 (4)	89 (5)	89 (19)
Making a Decision [a]	5, 6	88 (5)	89 (5)	90 (4)	88 (5)	89 (19)

[a] **= Assignment completed in cooperative learning groups of 3–4 students.**
[b] **= Assignment completed individually.**
[c] **= Higher *n* than other assignments this semester because, due to extenuating circumstances, one student completed this assignment individually.**

was 57.3% ± 15.3 (n = 65). For each semester in which Robert's World was utilized, the average exam scores for the lower-order exam in the PBL unit were significantly lower than the exam scores for lower-order exams from lecture-based units reviewing molecular biology and the principles of biotechnology (see Table 6). In comparison, there was no significant difference in any semester between the average scores for the molecular biology and biotechnology units (Table 6). The lower scores on the lower-order PBL exam conflicts with studies indicating gains in factual knowledge among students who had experienced a PBL unit, similar to those who had progressed through the same material using a lecture-based format (Dyke *et al.*, 2001).

Analyzing each question independently (see Table 7), students understood the differences and implications of multifactorial *vs.* unifactorial genetic diseases, demonstrated

TABLE 6. Average scores for Robert's World exam ("Exam 3") for each semester compared to average exam scores for two other exams (from other portions of the class taught via a lecture-based environment) for each semester. Exam 1 was over a review unit titled "Principles of Molecular Biology". Exam 2 was over a unit titled "Principles of Biotechnology" (that covered such areas as restriction enzymes, PCR, DNA fingerprinting, and transformation techniques). All statistical analyses were conducted using Student's 2-tailed *t* test (Steel and Torrie, 1960).

Semester	Exam No.	Avg. Score ± SD (n)	*P* when analyzed *vs.* Exam 1	*P* when analyzed *vs.* Exam 2	*P* when analyzed *vs.* Exam 3
Overall	**Exam 1**	**73.3 ± 16.2 (65)**	**—**	**0.202**	**5.3×10^{-8} ***
	Exam 2	**77.0 ± 16.7 (65)**	**0.202**	**—**	**1.3×10^{-10} ***
	Exam 3 (PBL)	**57.3 ± 15.3 (65)**	**5.3×10^{-8} ***	**1.3×10^{-10} ***	**—**
Summer 2004	Exam 1	69.3 ± 15.9 (18)	—	0.099	0.017 *
	Exam 2	78.0 ± 15.1 (18)	0.099	—	1.1×10^{-4} *
	Exam 3 (PBL)	56.7 ± 14.1 (18)	0.017 *	1.1×10^{-4} *	—
Fall 2004	Exam 1	70.3 ± 15.4 (18)	—	0.745	0.010 *
	Exam 2	72.1 ± 17.9 (18)	0.745	—	0.007 *
	Exam 3 (PBL)	56.1 ± 15.6 (18)	0.010 *	0.007 *	—
Spring 2005	Exam 1	82.6 ± 9.9 (13)	—	0.704	3.5×10^{-4} *
	Exam 2	84.3 ± 11.9 (13)	0.704	—	2.4×10^{-4} *
	Exam 3 (PBL)	58.9 ± 17.1 (13)	3.5×10^{-4} *	2.4×10^{-4} *	—
Summer 2005	Exam 1	73.7 ± 19.5 (16)	—	0.793	0.020 *
	Exam 2	75.5 ± 19.5 (16)	0.793	—	0.010 *
	Exam 3 (PBL)	58.1 ± 16.1 (16)	0.020 *	0.010 *	—

*** = $P < 0.05$.**

a strong ability to analyze restriction fragment length polymorphism (RFLP) banding patterns and had gained a solid understanding of the molecular biology basis of HD. However, they were far weaker in understanding the neurophysiological basis of HD, and in their knowledge of federal regulations regarding the actions of insurers and employers in what genetic tests can and can not be used for. Students demonstrated some understanding of the inheritance of genetic diseases, genetic counseling ethics and standards, and interpretation of the results of a genetic test for HD, although not at a desirable level. There is no correlation with the scores for similar authentic learning assignments (Table 5), in which students performed the strongest in reporting their knowledge about the nature of HD

TABLE 7. Scores for post-unit exams from 4 semesters that an immersive PBL unit was adopted. The percentage of students that answered each question correctly is indicated. Multiple entries in a row (*i.e.* 5A, 5B) indicate a case where WebCT had a choice of which question to use from a test bank (*note:* test bank option was discontinued beginning in Spring 2005 for Questions 5 and 11).

Wording of each question, answer choices, and correct answers are provided in Appendix B. All questions are multiple-choice, except for #3 (which is true/false).
Abbreviations: **HD=Huntington's disease; RFLP=restriction fragment length polymorphism; CAG=repeated cytosine-adenine-guanine DNA sequence involved in the development of HD**

Question Number	Knowledge Tested (Associated assignment)	% Correct in Summer 2004 (n)	% Correct in Fall 2004 (n)	% Correct in Spring 2005 (n)	% Correct in Summer 2005 (n)	% Correct: Weighted Avg. (n)
Overall	—	**57 (18)**	**56 (18)**	**59 (13)**	**58 (16)**	**57 (65)**
1	HD: Role of CAG repeats (Describing the Disease)	94 (18)	100 (18)	92 (13)	87 (16)	94 (65)
2	HD: Neurophysiological disease mechanism in brain (Describing the Disease)	5 (18)	22 (18)	15 (13)	25 (16)	17 (65)
3	Inheritance of HD (Describing the Disease)	50 (18)	61 (18)	69 (13)	62 (16)	60 (65)
4	Inheritance of genetic diseases (Genetic Diseases)	50 (18)	55 (18)	53 (13)	56 (16)	53 (65)
5A	Prevalence of multifactorial/ unifactorial genetic diseases (T/F) (Genetic Diseases)	85 (14)	77 (9)	69 (13)	81 (16)	78 (52)
5B		50 (4)	44 (9)	—	—	46 (13)
5 all		77 (18)	61 (18)	69 (13)	81 (16)	72 (65)
6	RFLP analysis (Genetic Testing)	100 (18)	88 (18)	100 (13)	81 (16)	92 (65)
7-8A*	Interpretation of HD genetic test (Genetic Testing)	63 (11)	77 (9)	40 (5)	60 (5)	63 (30)
7-8B*		33 (6)	57 (7)	88 (9)	85 (7)	68 (29)
7-8C*		50 (6)	44 (9)	75 (4)	63 (11)	56 (30)
7-8D*		83 (6)	50 (4)	66 (3)	80 (5)	72 (18)
7-8E*		14 (7)	14 (7)	40 (5)	25 (4)	22 (23)
7-8 all		50 (36)	50 (36)	65 (26)	65 (32)	57 (130)
9A	Federal legislation regulating insurers (9A) and employers (9B, 9C) (Making a Decision)	80 (5)	44 (9)	37 (8)	0 (8)	36 (30)
9B		0 (11)	0 (5)	20 (5)	37 (8)	14 (29)
9C		100 (2)	75 (4)	—	—	83 (6)
9 all		33 (18)	39 (18)	30 (13)	19 (16)	31 (65)
10A	Federal legislation regulating insurers (Making a Decision)	14 (14)	22 (9)	12 (8)	12 (8)	15 (39)
10B		25 (4)	11 (9)	60 (5)	50 (8)	35 (26)
10 all		16 (18)	17 (18)	30 (13)	31 (16)	23 (65)
11A	Genetic counseling ethics and standards (Genetic Counseling)	75 (4)	33 (9)	46 (13)	56 (16)	50 (42)
11B		78 (14)	100 (9)	—	—	87 (23)
11 all		77 (18)	67 (18)	46 (13)	56 (16)	63 (65)

*** WebCT was allowed to pick 2 questions from this set. These 2 questions constituted Questions 7 and 8 on the exam.**

in lay language, and in helping Robert make a decision in a logical and concise manner. This indicates that students are not effectively transferring their understanding from the contextualized higher-order learning to the more abstract lower-order recall. Overcontextualization of student knowledge is a constant concern in PBL. Most strategies to fight overcontextualization focus on presenting students with new novel cases (as we do with the "Genetic Counseling" assignment) and teaching students with abstract concepts rather than specific examples when providing them with information during the PBL segment of the course (reviewed in National Research Council, 2000).

In researching the nature of HD, students remembered learning about the genetic basis of HD, but were less proficient in the exam when asked to recall the neurophysiological mechanisms involved. Students understood RFLP analysis in the exam, but not the finer points of the pre-symptomatic HD test.

Why might students score so low on exams testing lower-level knowledge and comprehension with the PBL format? Perhaps they were overwhelmed with the information available in Robert's World. One theory proposes that learning takes place when a student, who otherwise might be complacent and unmotivated, is presented with information in such a way as to cause intellectual discomfort (Wankat and Oreovicz, 1991). In other words, in order to learn, students must first understand what they *don't* know (Bransford and Schwartz, 1998). In the process of learning, a student constructs an intellectual scaffolding that allows him or her to return to ease this intellectual discomfort.

In this study, the students generated their own discomfort by completing the "Defining the Issues" assignment, where they acknowledged the information Robert would need to accumulate in order to make an informed decision. They realized that not only would they need to learn much more about the human issues and ELSI surrounding Robert's dilemma, but they would also need to learn much more about the characteristics of genetic diseases and the techniques used in genetic testing. The instructor's role is that of a facilitator. He or she is responsible for the availability of student access to the information available that will allow the student to begin to construct an intellectual framework; however, the instructor should be careful not to provide too little or too much (Erlendsson, 2001). Robert's World contains a wealth of data and information (in their feedback, some students have suggested there is too much material). Accessing it in the different places (*e.g.* Robert's home or workplace, the genetic counseling office or genetic testing lab, *etc.*) requires time to click around as well as some familiarity with the geography of Robert's World. This means the student must have taken time earlier in the unit to "surf" around Robert's World to become familiar with the layout of where information is located. This is not a unit where a student can wait until the night before the exam, cram, and expect to do well. Indeed, like many on-line Internet delivery vehicles, Robert's World allows us to monitor student activity in Robert's World. During the semester in which we introduced Robert's World for the first time, the assignments were clustered together on a page outside Robert's World, rather than being embedded within Robert's World. We noticed during that semester that the majority of students were not entering Robert's World and were instead attempting to complete the assignments using resources they had located through external search engines. As a result, some of the assignments being submitted contained copious amounts of incorrect information and pseudoscientific rubbish. Robert's World began to be used extensively a few days before the unit exam (Figure 14). Following that experience, assignments were embedded within the geography of Robert's World, forcing students to "surf", and students are now using the features of Robert's World much more consistently throughout the entire unit (Figure 15). Correspondingly, the quality of the assignments is higher when student activity within Robert's World is spread out throughout the five weeks of the unit.

Robert's World may be so alien to students who are veterans of a more traditional format that they struggle in an environment in which they direct their learning to a greater degree than any format they have experienced before (Cruickshank and Olander, 2002). The use of Robert's World requires much more motivation on the student's part, as well as more work outside of class at a more steady pace (Herreid, 2000; Dyke *et al.*, 2001; Michel *et al.*, 2002), so time constraints may play another factor. Finally, if the development of higher-order understanding by the students is a goal, then assessment should be in the form of problems and opportunities that demonstrate the complexity of the student's thinking process (Wright *et al.*, 1998). A multiple-choice exam may not be the best measure of measuring student learning in a PBL format. Indeed, it has been suggested that the advantages of PBL might be manifested primarily in areas such as professional competence, life-long learning, and appreciation of the human and social sides of controversial issues (Shin *et al.*, 1993; Peters *et al.*, 2000; Michel *et al.*, 2002).

Robert's World fits the definition of a goal-based scenario. A goal-based scenario is one in which a student role-plays an individual who must accomplish a mission associated with his or her role in the scenario. The learning takes place when the student acquires particular skills and knowledge necessary to successfully complete the mission (Schank, 1997; Naidu *et al.*, 2000). In the students' case, their mission is to provide Robert with a recommendation as to whether or not he should take the genetic test for HD, when he should take it, and who should be involved in that decision (*e.g.* whether insurance should pay for

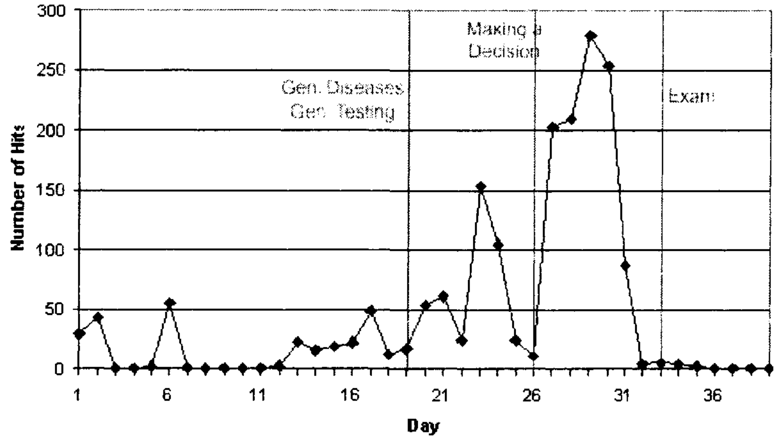

FIGURE 14. During the semester in which we first introduced Robert's World (Spring 2004), assignments were clustered together on a page outside Robert's World. We noticed very low utilization of Robert's World before the Genetic Diseases and Genetic Testing assignments were due and slightly higher before the Making a Decision assignment was due. Extensive use of Robert's World only occurred immediately before the exam was due. Exam scores this semester were not significantly different from exam scores in other semesters ($P \approx 0.12$). Assignment scores from this semester are not reported because the rubrics were still in development at this time. *Note:* Days 5–13 were Spring Break, though students, especially distance students, had access to Robert's World all through Spring Break.

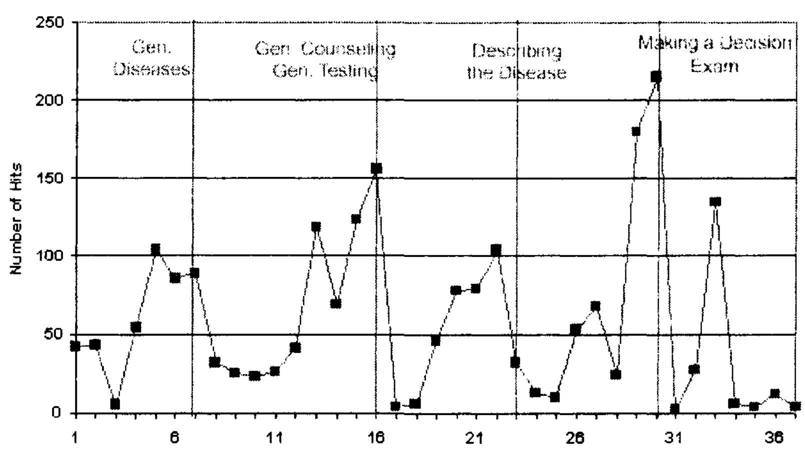

FIGURE 15. An example of a semester after assignments were embedded within Robert's World; in this case, Fall 2004. Students still tended to procrastinate, with the highest activity coming the day the exam was due (Day 30), the day before the exam was due (Day 29), the day that the Genetic Counseling and Genetic Testing assignments were due (Day 16), and the day that student responses to other groups' decisions were due (Day 33). Nevertheless, student activity is still more spread out than in Figure 14. We believe this difference is due to the placement of the assignments forcing the students to "surf".

and receive the results or Robert should pay for it out-of-pocket and then determine what to do with the results). The students' goal through the assignments is *not* to learn material for a lower-order multiple-choice exam (although that learning is hopefully a side-effect of the unit, as expressed in the unit objectives of understanding the nature and mode of genetic diseases and the principles of the technology used to diagnose them). This disconnect between the nature of the assignments and the nature of the exam may have contributed to a cognitive dissonance. There is a great deal of literature about the transfer of learning from a lower-order domain to the higher-order domains of problem solving, but very little about the reverse process. It is possible that the information learned in Robert's World is context-bound. Knowledge that is taught in a variety of contexts is more likely to support transfer than knowledge taught only in a single context (National Research Council, 2000). This may help explain not only the relatively low ability in some cases to translate students' higher-order learning into lower-order understanding of the neurophysiology of HD and the legal and ethical environment of genetic testing in the United States, but also the somewhat lower grades on the Genetic Counseling assignment compared to the other assignments (Table 7). The Genetic Counseling involved a great deal of mental transfer as students attempt to compare and contrast what they already know about HD with what they are learning (by research for this assignment) about gene-based breast cancer.

What were student reactions and attitudes concerning the immersive PBL environment? In any learning situation, student attitudes greatly impact the degree to which learning can occur (Henderleiter and Pringle, 1999). Student attitudes were determined using their responses to questions posed on the end-of-semester student evaluations concerning the effectiveness of Robert's World at achieving the learning objectives, the value of the assignments, and the usefulness of some of the resources available to the students. These questions are listed in Appendix C. Table 8 summarizes the quantitative responses to these questions.

Students were also given the opportunity to express what they liked the most and least about the unit, and what suggestions they had for the unit overall. In these essays, students were given free rein to express whatever they wanted; however, in reviewing their responses, a number of themes kept reappearing. A large number of students (13%) appreciated the realism of Robert's dilemma, and one expressed a feeling that he or she was doing good and helping somebody, even though Robert was a fictional person. A large group of students also reported increased appreciation of the issues from many different angles, especially the humanist aspect (11%), genetic disease aspect (9%), legal and ethical aspects (6%), and lab technique aspect (2%). Approximately 15% of the students reported that their favorite part of this unit was some aspect of working cooperatively as members of a team. Nearly 20%

TABLE 8. Student evaluation ratings in response to the problem-based learning unit in an on-line biotechnology class. Ratings are based on a scale of 1 (excellent) to 5 (poor).

	Rating Average ± SD	n
How well did we accomplish the following learning objectives:		
1. Understand the nature and mode of inheritance of genetic diseases	1.8 ± 0.8	63
2. Gain an appreciation of the human cost of genetic diseases	1.8 ± 0.7	63
3. Understand the principles and technologies used in genetic testing	2.0 ± 0.9	63
4. Gain an appreciation of ethical, legal, and social issues associated with genetic testing	1.8 ± 0.9	63
5. Develop problem solving skills	2.3 ± 0.9	63
We would like you to rate the effectiveness of the assignments in this unit:		
6. Defining the issues	2.2 ± 0.8	63
7. Genetic Diseases	2.0 ± 0.7	63
8. Genetic Counseling	2.3 ± 1.0	38
9. Genetic Testing	2.1 ± 0.8	63
10. Describing the Disease	2.0 ± 0.9	38
11. Making a Decision	2.3 ± 0.9	63

expressed special raves for the design of Robert's World as an immersive site that the students could wander and explore in a multidimensional fashion.

The most common dislike among students (reported by nearly 40% of the students in some form) was the cooperative learning. One of the great advantages of on-line learning is the flexibility of a student being able to "attend" class at any time of the day on any day of the week, and working at his or her own pace, within the limits of due dates placed periodically throughout the semester. Students with work and family commitments find this milieu especially appealing. In such an environment, being forced to work cooperatively is a surprise to many students, and they find themselves struggling to find times when they can "meet" synchronously. In theory, students can manage their cooperatively learning groups asynchronously, but it is often difficult through asynchronous communication to quickly allocate tasks and plan their problem-solving activities (Garrison and Anderson, 2003). Synchronous "meetings" can also be frustrating when one or more group members runs into technical problems such as Internet lag, low available bandwidth, or a computer crash. Another problem is the maxim that many students will do only the minimum amount of work necessary to achieve the grade they desire. Obviously, a student aiming for a "C" will have different amounts of commitment and motivation than a teammate aiming for an "A". One student went so far in their anonymous evaluation as to accuse their teammate of plagiarism for "lurking" in the chat room and not contributing anything valuable to the team's discussion and research. A variation on the commitment and motivation problem is that some students work best well in advance of deadlines, while other students will invariably wait until the last few hours before a deadline, which may cause a more studious teammate to panic. One student suggested that the instructor take a much more active role in keeping tighter control over "slackers". One solution to the problem of unequal student involvement is the use of periodic peer evaluation by each student's teammates (Conway, 2003). At the time of this writing, peer evaluations are being incorporated into each of the group assignments associated with Robert's World.

Not all of the dislikes cited by students were centered on teamwork, however. Some students (9%) felt that, after so many assignments and papers expressing higher-order learning, that a lower-order multiple-choice exam was unfair and inappropriate. Another common dislike was the six assignments due in five weeks. They felt the unit was too long and there were too many assignments (9%), with too short of a time to relax after each assignment was due (5%). Some students (8%) were frustrated at the design of Robert's World, feeling that the multidimensionality of Robert's World (as opposed to a linear list of lectures) was too complex, or were displeased at the balance of issues presented in Robert's World. A few students (3%) felt that the incorporation of ethical, legal, social, and human issues into what they perceived as a "hard science" course was inappropriate.

Overall, out of 63 students that have submitted evaluations discussing Robert's World, only two students explicitly suggested discarding Robert's World entirely and reverting to a lecture-based format. More common were positive sentiments that emphasized how much they learned about much more than just the technical aspects of a controversial new technology. Of those who submitted overall thoughts in general about Robert's World, 18% thought it was their favorite part of the class. One anonymous student summed up these feelings:

> "Overall it was a very good section. I spent quite a bit of time on it and was discussing it with many people outside of class and even outside the scientific field. I don't think I will ever forget that series."

Conclusion

Immersive PBL, in which students can interact with a fictional person with a definite sense of reality, is an appealing idea, an idea which can now be explored due to the unprecedented power of the Internet to make available to students a staggering amount of information and processing ability. But is immersive PBL conducive to learning? That depends on what one means by "learning." Immersive PBL seems to be helpful in stimulating higher-order learning. Higher-order learning does not take place on its own, however. As facilitator of the higher-order learning, the instructor has a vital role in designing assignments to guide the students in their learning. This role is more difficult than it sounds. Cruickshank and Olander (2002) noticed that highly-motivated students thrive in a PBL environment, while less-motivated students struggle with a variety of factors that they traditionally associate with the academic experience. Immersive PBL is no different – some students thrive and some students struggle. The richness of the multimedia landscape may be overwhelming when one is attempting to learn lower-order memorize-and-recall facts for a multiple-choice exam. An instructor who wishes to use immersive PBL in an on-line class should have in mind exactly what he or she expects the students to be able to do when the PBL unit is completed. If the goal is to simply learn facts, no matter what the field may be, immersive PBL may not be the most ideal (and is certainly not the most efficient) means to achieve that end. But if the goal is to help a student develop the ability to think, analyze, evaluate, learn, and solve the problems that he or she will encounter as a professional after graduation, immersive PBL is a valid implement for the educational toolkit.

Cruickshank and Olander (2002) suggest that a helpful development would be the institution of more PBL situations throughout the curriculum. This study strongly suggests that position is valid. One possibility for future research is to define specifically differences between a text-based PBL environment and an immersive PBL environment through a controlled study. Another question is when does multimedia immersion cross the line from being helpful to being a distraction that hinders learning? That depends on how used the student is to alternative modes of learning besides the traditional lecture-based instructor-centered approach. Determining where that line is between facilitation and distraction is a promising area for future research.

CHAPTER 6

CONCLUSIONS

On-Line PBL and Student Learning

Our results indicate that on-line PBL stimulates higher-order learning in students. This occurs in a text-based form of a PBL unit in which students are interacting intellectually with a purely imaginary situation, and with each other as a cooperative learning group. It is also occurring in a multidimensional immersive environment where the individuals involved are less evanescent (even if their physical forms are only that of actors), and where students have more interaction with material of a more "real" nature (such as the physical artifacts of forms, and the interviews with real experts). However, compared to a lecture-based format, lower-order learning did not increase.

There is an extensive literature showing that there is no significant difference between lecture-based student performance and PBL student performance on lower-level recall (using standardized exams) in a standard face-to-face environment (Wright *et al.*, 1998; Dyke *et al.*, 2001; Cruickshank and Olander, 2002; Michel *et al.*, 2002). There is also an extensive literature showing that there is no significant difference in learning between Internet-based lecture and face-to-face lecture environments (reviewed in Russell, 2001). Finally, students who complete biology courses in which guided writing is the central component perform better on standardized exams than students who learn the same material in a listening-to-a-lecturer format (R. Moore, 1992, 1993, 1994). One might be tempted to then conclude that there should be no significant difference, or perhaps slightly better performance, in student learning between a face-to-face PBL environment and an on-line PBL environment, especially one in which writing is the central component. However, the unusual situation of problem-solving in cooperative learning groups where the members never have direct personal contact creates circumstances which should force an instructor to pause and ask himself or herself, "What exactly do I mean by 'learning'? What do I really want the students to learn?"

The immense computing power of the Internet and advances in programming languages like Java and applications like Flash provide the potential to produce multimedia experiences that are more distracting than educational. The vast information content of the Internet can overwhelm even the most motivated student, not only relative neophytes, but even the most technologically-savvy student (Jensen *et al.*, 2002). The lack of content controls on the Internet means that pseudoscience and pornography have equal access to student's attention as scientifically responsible information (or better access, as pseudoscience doesn't have to go through the process of peer review). This doesn't mean that the Internet isn't an excellent place to implement PBL. It does mean that the instructor must be aware of the fine line he or she is walking between education and distraction.

A good example of this is the relatively low multiple-choice exam scores by students who had completed Robert's World (Tables 6 and 7). This exam (Appendix B) was completely different than the exam taken by students who had completed the text-based PBL unit (Appendix A), so valid comparisons between scores on these two exams cannot be made, but if we were to make the assumption that the difficulty of these two exams were the same, we would find that the results were significantly different ($P = 2 \times 10^{-18}$). An argument can be made that the exam detailed in Appendix B is considerably harder than the exam in Appendix A, but did the immersive Robert's World environment make a difference? But a more fundamental question is, does it matter that the students performed lower in regurgitation of lower-order factual knowledge?

The appropriateness of a multiple-choice exam over the recall of lower-order factual information is questionable (as approximately 9% of the students who completed Robert's World pointed out). Certainly any instructor wants his or her students to learn the factual information that forms the foundation of science, but the strength of PBL is in higher-order learning. As Wright *et al.* (1998) point out, "if developing higher-level thinking skills is a central goal, assessments must involve problems and provide opportunities where the complexity of the student's thinking process is exhibited." In both the text-based PBL unit and in Robert's World, many student groups did demonstrate considerable higher-order learning.

An interesting phenomenon is the difference in student performance between certain specific tasks in the papers they wrote, and very similar questions on the exam (Tables 5 and 7). This suggests that transference is not occurring between the specific contextualized tasks in the assignments and the more abstract lower-order recall required for the exam. One possibility is that for many cooperative groups, one student is doing most of the thinking while the rest of the students in each group are, as one student colorfully put it, "parasites". Equity of the division of labor is always a concern in any cooperative learning situation, but if this is the case in this course, the bulk of student groups are not reporting an unfair division of labor. Instead, we believe one problem may be due to overcontextualization of the problem. If students learn information only in one particular context, they often fail to transfer flexibly to new situations (Cognition and Technology Group at Vanderbilt, 1997). We attempted to avoid overcontextualization of the problem in Robert's World by assigning the Genetic Counseling assignment, in which individual students dealt with the problem of a woman coming in for genetic counseling for breast cancer, which is treatable and only partially genetic, both characteristics that make breast cancer quite different from Huntington disease. Another assignment meant to avoid overcontextualization of student learning on Huntington disease was the Genetic Diseases assignment, in which students conducted research about the mechanisms of inheritance, biochemistry, and physiology of another genetic disease, such as cystic fibrosis, phenylketonuria, or polycystic kidney disease, all of which are quite different from Huntington disease. One goal of both of these assignments was to help students to develop more abstract general principles that lead to more flexible transfer (Gick and Holyoak, 1983). Some students certainly made this transfer, and some did not. One remarkable fact about the scores for the Genetic Counseling assignment is the extraordinary standard deviation in the assignment scores. The average and standard deviation for this assignment for all four semesters that the Genetic Counseling assignment was used was 74.6% ± 21.0. In contrast, the overall averages were higher but the standard deviations lower for the Genetic Diseases (85.5% ± 11.3), Genetic Testing (82.7% ± 16.0), Describing the Disease (88.6% ± 7.0), and Making a Decision (88.8% ± 7.5) assignments.

Another possibility could be a weakness in the use of role-playing to immerse students more deeply in Robert's World. In Appendix B, Questions 9 and 10 both refer specifically to federal legislation. Knowledge of federal legislation is vital in completion of the "Making a Decision" assignment is one's group is role-playing the airline, the health insurance company, or, to a lesser degree, Robert. It is less vital if one is role-playing

Robert's 4-year-old daughter Andrea. Even though students are presumably paying attention to the on-line study guide for the exam that is provided for the students, it would be interesting to know if the students who role-played the insurance company or airline are scoring higher on these questions than the students who role-played Andrea or Angela. This could be a topic for future research.

It would also be interesting to correlate student exam scores with several factors about the students' educational experience, including their familiarity with on-line learning, their familiarity with PBL, and their previous coursework in genetics and molecular biology. Learning occurs when a student feels intellectual discomfort (Wankat and Oreovicz, 1991) because they come to realize what they don't know and need to know (Bransford and Schwartz, 1998), or because they have encountered contradictions that cannot be resolved with the knowledge they currently have (Perkins, 1991; Tobias, 1991). This discomfort is then eased by the construction of intellectual scaffolding that allows the student to then logically apply their knowledge to the resolution of the problem that generated the discomfort. The instructor's role is that of facilitator, by providing access to the knowledge that will form the scaffolding as well as designing the environment in which that access will occur. But on-line PBL, especially an immersive environment like Robert's World, is a very unique environment, one that most, if not all, students will never have encountered before. It is multimedia-rich, information-rich, and data-rich, and, in the case of Robert's World, the information and data is located at many different places around the virtual environment. Efficient use of this material requires a familiarity with Robert's World; a prerequisite for this familiarity is for the student to have "surfed" around Robert's World extensively beforehand, while completing previous assignments, or just for fun. This type of format may be so alien to some students who have succeeded in a more-traditional format that they struggle with this environment. Rather than having information "spoon-fed" to them, students must take the initiative and go out into Robert's World or the text-based PBL links and look for the information. As Cruickshank and Olander (2002) observed in their own PBL study, "Failing to recognize the provision of self-direction, half the students criticized the course for its lack of explicit instructions. These students were simply not aware of their own ability to conceive and produce quality work." Students take responsibility for their own learning (metacognition), and this added responsibility requires a great deal of motivation. Motivation is already a big problem in on-line classes – students may find an asynchronous class that they can log in to at night or on weekends appealing in theory, but they soon learn that spending their evenings or weekends taking a class rather than spending time with family or having fun is not as appealing in practice. All these factors may contribute to a student feeling "lost", and when "lost", a student's priority goes to finding out where they are and how to navigate to where they want to be, not to learning information. One can only help but wonder if this would be partially alleviated by previous student exposure to the PBL format. Cruickshank and Olander (2002) come to the same conclusion: "Instituting more problem-based laboratories…throughout the curriculum would help improve student performance." Nevertheless, future research could determine how much of the lower exam scores for Robert's World might be due to the unusual nature of the immersive PBL environment itself. Likewise, it is possible that previous "de-contextualization" of lower-level factual information in a more traditional lecture-based course focused on more-abstract concepts might offset the effects of overcontextualization, if overcontextualization is indeed a drawback to the immersive PBL format.

But if a multiple-choice exam isn't the ideal way of assessing student learning, what is? The assignments we have outlined are an obvious answer, but what else is an option? Wright *et al.* (1998) have an interesting way of assessing student learning in a format they term "student active learning" in a second-semester introductory-level chemistry course. They enlisted faculty members from science, mathematics, and engineering departments other than chemistry. These faculty members then gave 30-minute oral examinations to the students in which the assessors judged the competence of the students they examined. As Wright *et al.* (1998) say, "It was important that the assessment be done orally in order to probe student understanding and problem-solving ability. It was also important that the assessment involve external faculty who are independent of the course faculty." The assessors were allowed to make their own definitions of "student competence" and design their own oral examinations, but they had to provide written justification for their criteria in judging "competence", and they themselves were interviewed by the researchers to better understand the nature of their oral exams. This study also utilized student and faculty questionnaires, interviews, and surveys. The oral exams did not test mastery of subject matter, but instead emphasized the application of the material to new contexts. Wright *et al.* (1998) say, "the oral examinations reflect the scientific maturity of a student while traditional examinations reflect command of the subject matter." While the definition of "scientific maturity" is subjective at best, they did find that differences in perceived "student competence" or "scientific maturity" are correlated with the ability of students to demonstrate higher-order thinking skills. A similar strategy could be adopted for this biotechnology course. For distance students, however, this would have to be conducted using synchronous bandwidth-intensive audiovisual conferencing technology, something we have tried to avoid in the past due to the limited availability of high bandwidth in many areas and scheduling difficulties with non-traditional students who have jobs and family commitments. At-site proctors would still be required to monitor the testing environment, so this would require an additional commitment from recruited assessors (who may end up having to give the exams at night or on weekends) without any savings in commitment by students or proctors. In addition, this process would require a tremendous time commitment by the assessors. For instance, in a class with only 20 students, giving each student a 30-minute oral exam would require a 10-hour commitment. Nevertheless, other options to test student learning besides a lower-order multiple-choice exam may be a worthwhile course to pursue. Another option is to develop a higher-order multiple-choice exam, though these are difficult for the instructor to construct.

Student Attitudes about On-Line PBL

Student reaction to both PBL formats was overwhelmingly positive. The PBL environment provides a sense of realism and working for the good of something that is often not as apparent when one is listening to a lecture and absorbing neutral information. It also provides a humanistic aspect that is all-too-often forgotten in science education. For example, geneticists may get so caught up in the structure of the gene that they forget that this knowledge could be used to eliminate world hunger, or used to create a eugenics nightmare.

Cooperative learning also has a great appeal. Distance education is inherently an isolating activity. Instructors involved in distance education know all too well that it takes a tremendous amount of work and effort to create a virtual class, and much of that is spent trying to create a sense of a learning community. Yet all instructors know that it can never be the same as seeing all of one's classmates two or three times a week at the same place. Isolation saps motivation. Videoconferencing does nothing to alleviate this sense of isolation, and adds additional technical hurdles that must be overcome. But cooperative learning intimately puts students in contact with each other. Even if they never see each other, arguing over humanistic or social issues with his or her groupmates puts a student's logic, way of thinking, feelings, and emotions out there for all to see. In addition, being able to "bounce one's ideas off" an ally is a powerful way to learn (Jones, 1977; Thompson, 1981; Rice, 1998). There is a great deal of truth in the cliché, "two minds are better than one."

Yet there are inherent disadvantages to cooperative learning. All people differ in empathy for others, using their own emotions to facilitate thinking, understanding their own emotions, or being able to manage inappropriate emotions, qualities that have been termed by some psychologists and the popular media as "emotional intelligence" (Grewal and Salovey, 2005). A student's emotional intelligence is directly tied towards their ability to work with others, an ability often referred to in slang as "personal chemistry". Obviously, a lack of this "personal chemistry" yields a dysfunctional group that is not nearly as efficient as a smoothly-running group. It is nearly impossible for an instructor to determine from a distance how groups will work together. Students with similar backgrounds and experiences will often have a greater "personal chemistry" with each other, but the power of cooperative learning comes from mixing students heterogeneously, to expose them to points of view and ways of thinking quite different from their own.

A similar problem occurs when students have quite different expectations and goals in a class. Many students will only do the minimum necessary to get the grade they desire, and this can create conflict when one student is aiming for an "A" and a groupmate is aiming for a "C". In extreme cases, the "A" student may do the lion's share of the work, creating a situation where other students are "lurking" in the chat room or discussion forum and essentially being "parasites" off the "A" student's work. A variation on this theme is a student waiting until the last few hours to complete his or her work, which may cause his or her groupmates to panic, or to take the "slacker's" work upon themselves. Conway (2003) suggests solving the problem of unequal division of labor by instituting an individual peer review component of cooperative learning grades. However, the instructor should use such a system with caution. Students can easily agree not to hurt any groupmate's grade by failing to report honestly who is doing what and giving each other the same grade.

By far the most common problem with cooperative learning is scheduling. This is especially a concern in distance education, where many students are non-traditional students seeking to advance within their own career, or to obtain learning for another career. Asynchronous classes have the appealing aspect of allowing students to take classes when they want and where they want, often at nights or on weekends. But while cooperative learning can in theory be conducted asynchronously, it is often difficult to quickly allocate tasks or plan problem-solving abilities using only asynchronous communication (Garrison and Anderson, 2003). Synchronous communication requires juggling the students to juggle multiple schedules. Time zone differences are also a consideration many students fail to take into account. One group in our biotechnology class had a member in Germany. They scheduled their synchronous meetings for early in the afternoon Iowa time (a nightmare for group members who had jobs), which was late in the night for the student in Germany.

Technical problems unique to distance education also play a factor in student acceptance of PBL. High-bandwidth multimedia effects are impractical for many potential students who rely on dial-up modems, as is high-bandwidth videoconferencing technology. Arranging synchronous meetings can lead to a feeling of being "stood up" by another student who may not be able to log on (the dreaded "busy signal") or may be hindered by Internet lag. Of course, on-line PBL can also be ruined by the bane of any distance education student: computer crashes, hardware problems, software problems, and power outages.

Some students also express philosophical objections to PBL. This may be more of a concern in distance education than in a traditional on-campus class. The traditional young college student is often getting a liberal arts education, and an essential part of a liberal arts education is understanding the implications that the advance of scientific knowledge and technology has on society. They may be taking history concurrently or took it recently in the past, and the understanding of how knowing the structure of the atom led to the destruction of Hiroshima, or how the knowledge of Mendel's laws of genetics were twisted into Hitler's eugenics nightmare, may be fresh on their minds. On the other hand, in distance education, many non-traditional students are focused specifically on technical goals, such as how a technology works, and may consider ethical, legal, social, and human issues a waste of their time. Science without a strong sense of morality and the inviolability of human rights can be terrifying, as the history of Nazi Germany and the Soviet Union illustrate. Yet some students have a narrow definition of what "science" is, and they may express distaste for the ELSI focus and the higher-order learning that is inherent to PBL.

Finally, another concern that students may have revolves around the complexity of the PBL unit itself. This is more of a concern with immersive PBL than with text-based PBL. This may be tied to a (possibly subconscious) technophobia on the part of the student, or may be a result of simply being overwhelmed by the richness of an immersive PBL environment. Technophobia, though most often associated with students who have limited exposure to computers, also exists among some students who have extensive experience with computers and are technologically savvy (Jensen *et al.*, 2002). This is one aspect of PBL that is actually less of a concern in on-line PBL than in cases where students are conducting on-line research for face-to-face PBL. After all, why would a technophobe want to take an entire class through the Internet, where every aspect of the class takes place at a computer? Nevertheless, the complexity of the PBL environment must be kept in mind when an instructor is developing a class with a PBL format.

Recommendations for Adopting PBL in an On-Line Class

These conclusions lead to a number of things that an instructor should keep in mind when implementing either a PBL on-line course or a PBL unit within an on-line course. Some are PBL-specific; others are useful in any on-line course utilizing any format of student learning.

1) *What does the instructor want the students to learn?* If the instructor intends students to learn how to think, how to learn (metacognition), and how to analyze and evaluate ethical, social, and human issues, he or she will need to design the environment and the assessments to emphasize those aspects. Our experience suggests that students had a greater appreciation of these "softer" aspects of biotechnology from the immersive PBL environment, but learned more about the "hard" aspects of the technology and biological aspects of genetic diseases from the text-based PBL unit. PBL has its strengths and weaknesses. An instructor should exploit the strengths of PBL, and downplay the importance of things (such as lower-order learning) that PBL is not geared to address.

2) ***Nearly anything is possible on the Internet, and if it's not possible now, it soon will be.*** An on-line PBL course cannot be and should not be the answer to everything wrong with a class, but it can be the answer to nearly any one thing that may be wrong with a class, if designed properly. If an instructor tries to do everything with PBL (such as promoting lower-order learning as well as higher-order learning), he or she is likely to overwhelm the student. The temptation to do more and more and more with the help of the Internet will increase as we move closer to Taylor's "fourth and fifth generations" (Taylor, 1995, 2001) and Berners-Lee *et al.*'s (2001) "Semantic Web". The ultimate expression of being able to do anything will come later in the 21st Century with the first PBL unit in virtual reality. Our experience with Robert's World can be extrapolated to indicate that virtual reality may increase higher-order learning. But if student learning of lower-order material may be hindered in part by the environment of Robert's World, will virtual reality work any better in helping students learn lower-order material? If students have trouble locating information by clicking back and forth between Robert's home and genetic counselor's office and the library, will actually "going" to Robert's home and library offer any advantages? Maybe, but maybe not. Just because something is realistic and aesthetically pleasing doesn't necessarily mean that it works.

3) ***Keep the audience's technical capabilities in mind.*** The temptation exists to incorporate every state-of-the-art technological development that comes along in an effort to make PBL more immersive, more realistic, and more engaging for the students. But especially for a largely-rural potential student population like we have in Iowa, remember that your students may not have the capability to exploit state-of-the-art technology. The pressure today in the distance education community is to incorporate high-bandwidth synchronous videoconferencing technology into on-line PBL, but adoption of this technology is prohibitive for students who are dialing up on 56k modems. Perhaps in a few years, the majority of Internet users will have access through DSL or cable modems, but who's to say that those high-bandwidth connections won't be made obsolete by wireless technology? The Iowa Communications Network is a cautionary tale about a technology becoming obsolete before its infrastructure can even be built. In the meantime, it is probably prudent to assume that the majority of students are 5–10 years behind "state of the art".

4) ***Students can never write too much.*** Yes, this can be taken to an extreme, and some students complain that we have already crossed this limit with six papers due in five weeks. But, other than voice-to-voice personal communication, there is no other way besides writing to determine higher-order learning, which is PBL's ultimate strength. The ways that writing helps student learning, especially in a cooperative learning environment, are myriad, and are discussed in detail in Chapter 3. Just make sure they have time to complete all the assignments.

5) ***Be consistent in how to assess student goals.*** The students' goals in both PBL environments was to acquire skills and knowledge necessary to help Robert make his decision, and if the decision is to indeed get the test, when it should be done and who should

be made aware of the results. This fits the definition of a goal-based scenario (Schank, 1997; Naidu *et al.*, 2000). The students' goal was not to learn material for lower-level recall on a multiple-choice exam. One can certainly hope that learning of lower-order material is a side-effect of higher-order learning, but relatively little is known about transference of learning from a higher-order domain of learning to a lower-order domain of learning. There are other options to test student knowledge besides multiple-choice exams, including the writing of essays, performing of authentic tasks, and so forth. Multiple-choice exams can be constructed that specifically test higher-order learning (though the construction of such exams is difficult). The possibility of using those other options should be explored.

6) *Avoid overcontextualization.* Overcontextualization is a constant and long-recognized danger in PBL (Gick and Holyoak, 1983; Cognition and Technology Group at Vanderbilt, 1997; Bransford *et al.*, 1998; National Research Council, 2000). Students may become the campus' leading experts in, say, Huntington disease, but if they can't transfer that understanding to other relevant contexts, then why bother? An instructor must have some way of determining transferability of their understanding (as we do with the Genetic Counseling assignment). One possibility may be to implement "mini-PBL's" within the larger, more encompassing PBL environment.

7) *The instructor should make sure that he or she facilitates student access to the material they need.* Students shouldn't be actively prohibited from conducting research by using external search engines (especially if they know what they're doing, like using Google Scholar instead of Google), but if the instructor has provided the ability for students to access the information they need within the PBL environment, that's a powerful way to guide student learning towards desired outcomes. It also prevents students from reporting information of questionable veracity. For certain subjects in biology (like anything dealing with reproduction, evolution, or astrobiology), it's often nearly impossible for students on their own to wade through the oceans of pornography or pseudoscience returned by most search engines in order to find the nuggets of respectable science. This also gives the instructor the ability to limit the amount of information within the PBL environment, which may prevent students from feeling totally overwhelmed by a sea of information.

8) ***Be careful with assigning groups to role-play certain characters.*** The use of role-playing in Robert's World, we believe, facilitated student engagement with the characters and provided an opportunity for student exchanges which demonstrated that they had really internalized the ethical, legal, social, and human concerns surrounding genetic diseases. Plus, it was entertaining from the instructor's point of view to read all these exchanges. However, it is unknown whether certain students becoming proficient in certain areas of knowledge in order to play their roles gave them an unfair advantage over other students when exam questions dealt with those areas of knowledge without testing other areas of knowledge that other characters might know more about. Until that has been determined, role-playing should be used with caution.

9) ***Remind students constantly that working in cooperative groups takes a lot of effort from everybody involved. This includes the instructor.*** So-called "emotional intelligence" isn't instinctual or innate. It must be cultured and developed by listening, questioning, active attempts at tolerance, and putting oneself into another's shoes. Students have to be reminded of this constantly, and effort should be made to teach students what is required in truly cooperative learning. In cooperative learning, the instructor's roles include those of counselor, referee, mediator, priest, psychologist, coach, advisor, arbitrator, censor, and judge. The bulk of an instructor's e-mail from students during a PBL unit will often be students complaining about their groupmates. In extreme cases (like a group member who disappears for an extended period of time, or in cases of overt verbal abuse), it may be necessary to expel a member from a cooperative learning group. But in many cases, interpersonal differences can be ameliorated with instructor mediation.

10) ***Nothing even remotely tied to science should be immediately excluded from a science class simply because it's not "pure science."*** One of the fascinating things about PBL is its ability to emphasize scientific subjects in a humanistic aspect in a much more immediately "real" fashion to students. It's one thing for a student to hear an lecturer say, "Huntington disease patients have a difficult decision to make whether they want to obtain DNA testing since there is no treatment and no cure should they test positive." It's quite another thing for a student to help Robert make this very decision. Science is intimately tied up with the society in which that science exists. We cannot learn about the power of nuclear energy without remembering that that very power could be used to destroy our civilization. Many other fields of science, especially biotechnology, have equally sobering implications in the greater scheme of human society, especially when one remembers how easily humanity's dark side has been manifested throughout history.

11) ***Use peer evaluation to assess student division of labor, but establish clear guidelines on the use of peer evaluation.*** After teaching students how to cooperate in a cooperative learning environment, there is no better tool to ensure each individual student is deserving of the grade they are receiving than to have their groupmates, who are most familiar with their group's division of labor and interpersonal "chemistry", make that decision. But giving a student's groupmates that kind of power also means that power can be abused. For instance, it is considered unethical for all members of a student group to agree to the same rating for every member (Conway, 2003). In addition, peer evaluation should never be the main determination of a student's grade. What the group actually produces should matter for the greater part of the student's grade. Currently, peer evaluation is being used in Robert's World for the Defining the Issues, Genetic Diseases, and Making a Decision assignments. The process is underway to also incorporate peer evaluation into the Genetic Testing and Describing the Disease assignments.

12) ***Make sure students have access to both asynchronous and synchronous communication within your course architecture.*** Some students prefer asynchronous communication, even in a cooperative learning format. Some students prefer synchronous communication. Both should be available without forcing students to, for example, download an instant messaging system. They shouldn't be prohibited from doing so if they wish, but it shouldn't be required simply because the class architecture doesn't support synchronous communication. The quintessence of distance education is flexibility. That flexibility should be supported in every aspect of the class as much as possible, especially in a format like on-line PBL in which temporal flexibility is sacrificed.

Final Conclusions

Our results indicate that PBL is a justifiable tool in on-line classes for stimulating higher-order learning; especially in the ethical, legal, social, and human aspects of whatever field the course happens to be about. We are not aware of any factors that would prohibit PBL from being incorporated into any on-line course in which higher-order learning is desirable. On-line PBL does not increase lower-order learning in our particular case. This agrees with the literature regarding face-to-face PBL. However, we observed a decrease in the learning of lower-order factual knowledge in students completing either on-line PBL unit, for reasons yet to be empirically determined. The decreases we observed may be due to the exams used, or may be due to the nature of the immersive PBL unit itself. Nevertheless, we feel that the advantages of PBL outweigh, or at least balance, the disadvantages. The instructor should be aware of certain characteristics which are different between face-to-face PBL and on-line PBL, such as magnified problems with cooperative learning groups in on-line PBL (scheduling synchronous communication, interpersonal relationships, instructor monitoring, and so forth). As distance education becomes more important to the mission of higher education institutions in the 21st Century, it is our hope that PBL is adopted as a widespread means for increasing the quality of on-line science education both in the United States and around the world.

APPENDIX A

EXAM QUESTIONS FOR THE TEXT-BASED PBL UNIT

The following questions were used as the post-unit exam for text-based PBL unit (see Chapter 4). A few of the multiple-choice numbers for which there are multiple questions that could be randomly taken from the test bank were used for the all-multiple-choice pre-unit exam. Multiple questions for each number mean that students would not necessarily see the same questions between the pre-unit and post-unit exams. It also means that students would not be able to share answers outside of the testing facility, if they should know each other outside of class (the asynchronous nature of the on-line class means that students will be taking the exam at different times, depending on their own schedules).

This particular version of the exam appeared in Spring 2001, and is representative of the exams for the text-based PBL unit. Not all of these questions are directly relevant to the research material, because back in 2001, and a few years before and since, material on certain molecular biology techniques (restriction enzymes, electrophoresis, PCR, DNA fingerprinting, *etc.*) was included in the PBL unit. But since the data in Chapter 4 considers overall scores on this exam, all questions are provided below.

Each *different* question (representing the different questions that each individual student would see) is represented by a different number (**1, 2, 3**, *etc.*). Each different possible question in the *multiple questions* (where different students might see different questions, or one student might see different questions between the pre-unit and post-unit exam) is represented by a number with an upper-case letter (**1A, 1B**, *etc.*). Possible answers for a multiple-choice question are indicated with lower-case letters. A star (*) indicates the correct answer.

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1 – 16) Questions 1 – 16 are worth 5 points each. *[Total exam is 200 points.]*

1A) Cystic fibrosis (CF) is an autosomal recessive unifactorial genetic disease. Two non-CF parents have five children. One of these children has CF; four do not. The mother is pregnant for a sixth time. What is the probability that their next child will have CF?

- **a)** less than 1% (the probability of a random mutation; these parents would normally not be able to have a CF child)
- **b)** 25% *
- **c)** 50%
- **d)** 75%
- **e)** unknown; we would first need to know the child's sex

1B) Consider Robert, the protagonist of our Huntington's Disease scenario in Module 3. Huntington's Disease (HD) is an autosomal dominant unifactorial genetic disease. Robert's mother Martha died of complications from HD at age 50. Robert has a young daughter named Andrea. *Without knowing Robert's genotype*, what is the probability that Andrea will someday contract HD? Assume that Andrea's mother has no history of HD in her family, and neither did Robert's father.

a) less than 1% (the probability of a random mutation)
b) 25% *
c) 50%
d) 75%
e) 100%

2) Hemophilia is a unifactorial X-linked genetic disorder. A normal woman, whose father had hemophilia, is pregnant. The child's father is also hemophiliac. What is the probability that the child will be hemophiliac?

a) less than 1% (the probability of a random mutation)
b) 25%
c) 50% *
d) 100%
e) unknown; we would first need to know the child's sex

3A) Multifactorial genetic diseases, because they involve many defective genes, are typically very rare in the population.

a) true
b) false *

3B) Unifactorial genetic diseases, because they only involve a single defective gene with little, if any, environmental influences, are typically very rare in the population.

a) true *
b) false

4) The polymerase chain reaction is important because it allows us to:

a) insert eukaryotic genes into prokaryotic plasmids.
b) incorporate genes into viruses.
c) make DNA from RNA transcripts.
d) make many copies of DNA. *
e) insert regulatory sequences into eukaryotic genes.

5A) Which enzyme is used to make multiple copies of genes in the polymerase chain reaction (PCR)?

- **a)** restriction endonuclease
- **b)** poly A polymerase
- **c)** reverse transcriptase
- **d)** RNA polymerase
- **e)** DNA polymerase *

5B) *Eco*RI is an example of which type of enzyme?

- **a)** DNA ligase
- **b)** DNA polymerase
- **c)** restriction enzyme *
- **d)** reverse transcriptase
- **e)** RNA polymerase

6A) You have a single-stranded DNA probe that is 14 bases long. What is the probability that this probe will bind to a randomly picked sequence of 14 bases in the genome?

- **a)** 1.34×10^{-4}
- **b)** 2.68×10^{-8}
- **c)** 5.96×10^{-8}
- **d)** 3.73×10^{-9} *
- **e)** cannot be determined from the information given

6B) The recognition sequence for a restriction enzyme is 7 bp long. What is the probability this enzyme will cleave a random DNA sequence of 7 bp?

- **a)** 6.1×10^{-5} *
- **b)** 0.14
- **c)** 3.2×10^{-10}
- **d)** 4.2×10^{-4}
- **e)** cannot be determined from the information given

7A) Which of the following procedures would produce RFLPs?

- **a)** incubating a mixture of single strand DNA from two closely related species
- **b)** incubating DNA nucleotides with DNA polymerase
- **c)** incubating DNA with restriction enzymes *
- **d)** incubating RNA with DNA nucleotides and reverse transcriptase
- **e)** incubating DNA fragments with "overhanging ends" with ligase

7B) A DNA fingerprint is produced by

a) treating selected segments of DNA with restriction enzymes.
b) electrophoresis of restriction fragments.
c) oligonucleotides created via PCR.
d) electroporation of cDNAs.
e) Both answers 1 and 2 are correct. *

8) If you discovered a bacterial cell that contained no restriction enzymes, which of the following would you expect to happen?

a) The cell would be unable to replicate its DNA.
b) The cell would create incomplete plasmids.
c) The cell would be easily infected by bacterial viruses. *
d) The cell would become an obligate parasite on other organisms.
e) Both c and d would occur.

9) How does a bacterium protect its own DNA from being attacked by its own restriction enzymes?

a) The bacterium acetylates its own DNA.
b) The bacterium methylates its own DNA. *
c) The bacterium stores its own DNA in a single-stranded form that is resistant to the restriction enzyme.
d) The restriction enzyme is inactive until needed.
e) Special enzymes rebuild restriction enzyme damage in the bacterial DNA.

10) Which of the following sequence from a double-stranded DNA molecule may be recognized as a restriction site for a particular restriction enzyme? (*i.e.:* Which exhibits the sequence characteristics of a restriction site?)

a)	AAGG TTCC	**c)**	GGCC * CCGG	**e)**	AAAA TTTT
b)	AGTC TCAG	**d)**	ACCA TGGT		

11A) Which of the following separates molecules by movement due to their size and electrical charge?

a) restriction enzyme
b) gene cloning
c) DNA ligase
d) gel electrophoresis *
e) reverse transcriptase

11B) Which of the following is used to locate or identify DNA molecules containing a particular DNA sequence?

- **a)** gel electrophoresis
- **b)** DNA probe *
- **c)** mutation
- **d)** PCR
- **e)** restriction enzyme

12) What is the genetic function of restriction enzymes?

- **a)** adds new nucleotides to the growing strand of DNA
- **b)** joins nucleotides during replication
- **c)** joins nucleotides during transcription
- **d)** cleaves nucleic acids at specific sites *
- **e)** repairs breaks in sugar-phosphate backbones

13) Why do we use the polymerase from a rare bacterium like *Thermus aquaticus* in PCR rather than the polymerase from *E. coli* or another common bacterium?

- **a)** The *T. aquaticus* polymerase is simpler and easier to manipulate.
- **b)** The *T. aquaticus* polymerase is cheaper.
- **c)** The *T. aquaticus* polymerase replicates DNA faster than polymerase from any other species.
- **d)** The *T. aquaticus* polymerase is resistant to the heat used in PCR. *
- **e)** None of the above.

14A) Transferring electrophoresed DNA bands to a nylon membrane for visualization with radioactive probes is known as:

- **a)** Northern blotting
- **b)** Eastern blotting
- **c)** Southern blotting *
- **d)** Western blotting
- **e)** Northwestern blotting

14B) DNA fragments from a gel are transferred to a membrane via a procedure called Southern blotting. The purpose of Southern blotting is to:

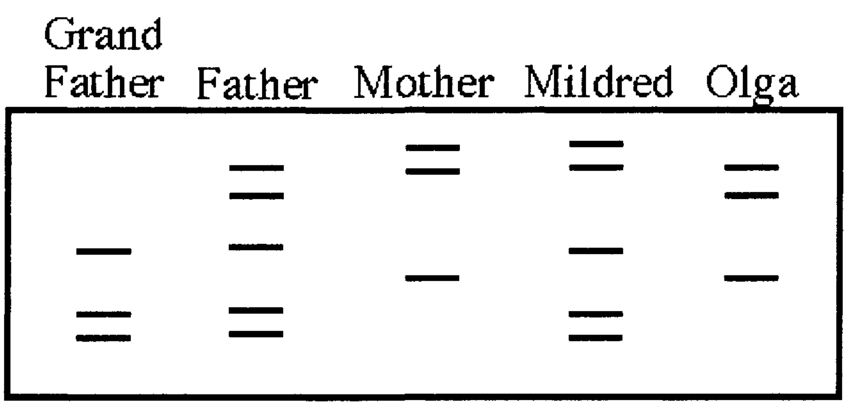
- **a)** permanently attach the DNA fragments to a substrate for later visualization. *
- **b)** separate the two complementary strands.
- **c)** analyze the RFLPs in the DNA.
- **d)** separate out the PCR products.
- **e)** separate DNA fragments based on their electrical charge.

15) What does the pattern of bars in a DNA fingerprint represent?
- **a)** the order of bases in a particular gene
- **b)** the individual's genotype
- **c)** the presence of dominant or recessive alleles
- **d)** the presence of certain DNA fragments *
- **e)** none of the above

16) What is the correct order of the steps in the PCR reaction?
- **a)** bind primers, copy DNA, denature DNA
- **b)** denature DNA, copy DNA, bind primers
- **c)** copy DNA, bind primers, denature DNA
- **d)** bind primers, denature DNA, copy DNA
- **e)** denature DNA, bind primers, copy DNA *

17 – 18) Questions 17 – 18 are worth 10 points each. *[Total exam is 200 points.]*

17) Mildred and Olga are two sisters who come from a family with a history of cystic fibrosis (CF) on their father's side of the family. Their paternal grandfather had CF (genotype *cc*), but their father did not (genotype *Cc*). Neither Mildred nor Olga has CF, and there is no history of CF anywhere in their mother's family (assume mother's genotype is *CC*). The inheritance of the region around the CF gene on chromosome 7 was tracked using RFLP analysis (assume 100% linkage between the RFLP and the CF gene), and the resulting bands are shown below. Which of the statements below is true?



- **a)** Mildred and Olga are both carriers of the defective CF gene.
- **b)** Mildred is a carrier of the defective CF gene but Olga is not. *
- **c)** Olga is a carrier of the defective CF gene but Mildred is not.
- **d)** Neither Mildred nor Olga is a carrier of the defective CF gene.
- **e)** It cannot be determined from the data whether Mildred or Olga are carriers of the defective CF gene.

18) Briefly explain why "wild" bacterial cells (*i.e.:* outside the laboratory; in Nature) contain restriction enzymes.

* *They help defend the cell against attack by bacteriophages (bacterial viruses) by cleaving phage (viral) DNA.*

19) Question 19 is worth 20 points.

19) You wish to map the recognition sites for two restriction enzymes, *Eco*RI and *Bam*HI, on a 10-kb linear DNA segment. You cleave the DNA with these enzymes and then electrophorese the digestion products, which yields the following results

*Eco*RI alone:	a 3 kb and a 7 kb fragment
*Bam*HI alone:	0.5 kb, 1 kb, and 8.5 kb fragments
*Eco*RI and *Bam*HI:	0.5 kb, 1 kb, 2 kb, and 6.5 kb fragments

Develop a map (not a picture of the gel) of the locations of the recognition sites for *Eco*RI and *Bam*HI. List the distances of the recognition sites from the end of the DNA molecule and the name of the restriction enzyme that cuts at the site (*i.e.:* describe or list distances between ends of fragments and restriction sites and between different restriction sites in text format, or draw map in ASCII and label).

* *End – 1 kb –* Bam*HI – 2 kb –* Eco*RI – 6.5 kb –* Bam*HI – 0.5 kb – End*

20 – 21) Questions 20 – 21 are worth 15 points each.

20) What is meant by denaturation of DNA? Give two treatments that can be used to denature DNA.

* *Separation of double-stranded DNA into two molecules of single-stranded DNA by breaking of the hydrogen bonds between the base pairs. May be accomplished by increasing temperature, pH, or concentrations of compounds such as urea or formaldehyde.*

21) A paleontologist has recovered a bit of preserved tissue from the carcass of a 10,000-year-old frozen woolly mammoth. She would like to compare DNA from the sample with DNA from living elephants. How might she go about increasing the amount of DNA available for testing? Describe IN DETAIL the procedure she would use.

* *Describe the story of PCR (in significantly more detail than this "answer" does.*

22 – 23) Questions 22 – 23 are worth 10 points each.

22) You want to amplify the part of the DNA molecule shown below using PCR. The two PCR primers are also shown. Show the newly-replicated products of the reaction after the first PCR cycle.

```
5'-A G C C T G A T T A C G C T G C A C G G G A A A T T C-3'
3'-T C G G A C T A A T G C G A C G T G C C C T T T A A G-5'

Primer 1:  5'-C C C G-3'
Primer 2:  5'-G A T T-3'
```

* *3' TCGGACTAATGCGACGTGCCC 5'*
5' GATTACGCTGCACGGGAAATTC 3'

23) Starting with one molecule of DNA, how many molecules of DNA can be produced in 2 hours using PCR? (Assume one complete cycle of denaturing, annealing, and copying takes 5 minutes)

* *2 hours = 120 minutes = 24 cycles; thus* $2^{25} = 3{,}354{,}432 = 3.36 \times 10^{7}$

24 – 25) Questions 24 – 25 are worth 15 points each.

24) What are some of the techniques presented in Module 3 that could be used to detect the presence of bacterial and viral pathogens in infected host cells?

* *Use DNA probe unique to bacterial or viral genome. OR Conduct PCR using primers unique to bacterial or viral genome.*

25A) Consider Robert, the protagonist from our Huntington's Disease saga in Module 3. Suppose he decides to get the Huntington's Disease test, and he is found to be positive for the Huntington's allele. His employer-based health insurance company, which paid for the test, finds out that Robert is positive for the Huntington's allele, and cancels his insurance, citing the presence of the Huntington's allele as a pre-existing condition. Under federal law, are the insurance company's actions legal? Why or why not?

* *No. The Health Insurance Portability and Accountability Act of 1996 (HIPAA) prohibits employer-based and commercially-issued group health insurance plans from using any genetically-derived information for denying or limiting eligibility. The act also prohibits them from considering the presence of alleles in the absence of a current diagnosis of illness as a pre-existing condition. However, it should be noted that there is no law protecting customers who get individual coverage, rather than through their employer. As far as obtaining the data, the insurance company did nothing wrong there under federal law. There are no federal laws protecting the security and privacy of genetic tests given to individuals, although many states have such laws.*

25B) Consider Robert, the protagonist from our Huntington's Disease saga in Module 3. Suppose he decides to get the Huntington's Disease test, and he is found to be positive for the Huntington's allele. His employer, the airline (a private corporation), finds out that Robert is positive for the Huntington's allele, and transfers him to a desk job without his consent. Under federal law, are the airline's actions legal? Why or why not?

** Yes. There are no federal laws prohibiting an employer from gaining access to relevant genetic testing results, although some states do have laws. And there are no laws prohibiting a private corporation from requiring genetic testing and from using such data to determine job placement. Federal agencies are, on the other hand, barred from such activities under an executive order signed by President Clinton in 2000. It should also be noted that when Robert's symptoms become apparent and he can be diagnosed with Huntington's Disease, he may be able to be protected by the Americans with Disabilities Act, but by that time, he would not be able to get his flying job back due to safety concerns.*

APPENDIX B

EXAM QUESTIONS FOR ROBERT'S WORLD

The following questions were used as the post-unit exam for the immersive PBL unit (Robert's World; see Chapter 5). Multiple possibilities for a question (*e*.g. **5A** *vs*. **5B**) indicate WebCT was able to choose randomly between these possibilities, reducing the probability that students might share answers outside of the testing facility, if they should know each other outside of class (the asynchronous nature of the on-line class means that students will be taking the exam at different times, depending on their own schedules). All questions were multiple-choice questions, except for **5**, which was a true/false question. A star (*) indicates the correct answer.

---

1) (10 points) Which of the following statements is true about an individual who develops Huntington Disease as a teenager?

- **a)** The defect is likely due to a spontaneous mutation in the *huntingtin* gene
- **b)** The individual has a large expansion of the CGG repeat next to the CAG repeat
- **c)** The early expression of the disease is likely due to environmental factors
- **d)** The individual has a large expansion of the CAG repeat *
- **e)** None of the above

2) (10 points) Which of the following statements about Huntington Disease is false?

- **a)** Huntington Disease results from the death of neurons in the striatum of the basal ganglia
- **b)** A region in the *Huntington* protein containing multiple glutamine residues is expanded
- **c)** The *huntingtin* protein is clipped and a fragment of the protein migrates to the nucleus
- **d)** Expansion of the glutamine region of huntingtin changes the shape of the protein
- **e)** Clumping of the protein fragment in the nucleus of neurons causes cell death *

3) (10 points) Consider Robert, the protagonist of our Huntington's Disease scenario. Huntington's Disease (HD) is an autosomal dominant unifactorial genetic disease. Robert's mother Martha died of complications from HD at age 50. Robert has a young daughter named Andrea. *Without knowing Robert's genotype*, what is the probability that Andrea will someday contract HD? Assume that Andrea's mother has no history of HD in her family, and neither did Robert's father.

a) less than 1% (the probability of a random mutation)
b) 25% *
c) 50%
d) 75%
e) 100%

4) (10 points) Hemophilia is a unifactorial X-linked genetic disorder. A normal woman, whose father had hemophilia, is pregnant. The child's father is also hemophiliac. What is the probability that the child will be hemophiliac?

a) less than 1% (the probability of a random mutation)
b) 25%
c) 50% *
d) 100%
e) unknown; we would first need to know the child's sex

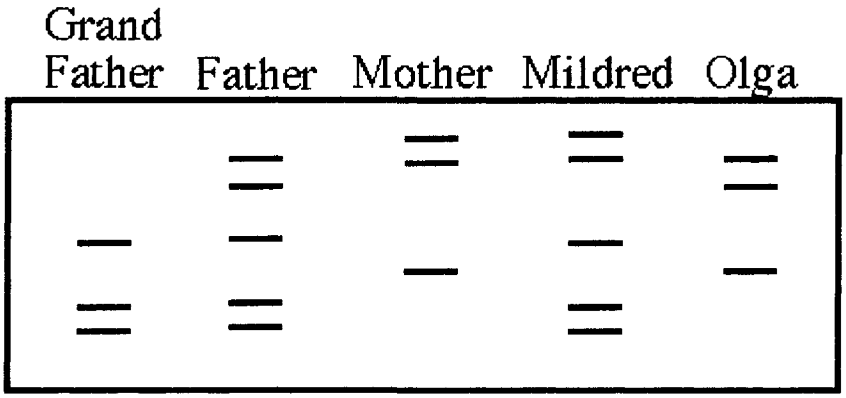
5A) (5 points) Multifactorial genetic diseases, because they involve many defective genes, are typically very rare in the population.

a) true
b) false *

5B) (5 points) Unifactorial genetic diseases, because they only involve a single defective gene with little, if any, environmental influences, are typically very rare in the population.

a) true *
b) false

6) (10 points) Mildred and Olga are two sisters who come from a family with a history of cystic fibrosis (CF) on their father's side of the family. Their paternal grandfather had CF (genotype *cc*), but their father did not (genotype *Cc*). Neither Mildred nor Olga has CF, and there is no history of CF anywhere in their mother's family (assume mother's genotype is *CC*). The inheritance of the region around the CF gene on chromosome 7 was tracked using RFLP analysis (assume 100% linkage between the RFLP and the CF gene), and the resulting bands are shown below. Which of the statements below is true?



- **a)** Mildred and Olga are both carriers of the defective CF gene.
- **b)** Mildred is a carrier of the defective CF gene but Olga is not. *
- **c)** Olga is a carrier of the defective CF gene but Mildred is not.
- **d)** Neither Mildred nor Olga is a carrier of the defective CF gene.
- **e)** It cannot be determined from the data whether Mildred or Olga are carriers of the defective CF gene.

[7 – 8: There are 5 variations on this question. Two of the following questions appeared as 7 and 8.]

7–8A) (10 points) Imagine that Robert decides to have the genetic test for Huntington Disease. The report shows two peaks (17 and 19 repeats). What can you conclude about this test result?

- **a)** Robert is normal and will not develop Huntington Disease *
- **b)** Robert is at risk for developing Huntington Disease but there is a good chance that he will not develop the disease.
- **c)** Robert is almost certain to develop Huntington Disease
- **d)** Robert is not likely to develop Huntington Disease but his daughter, Andrea, may develop the disease.
- **e)** The test is inconclusive

7–8B) (10 points) Imagine that Robert decides to have the genetic test for Huntington Disease. The report shows two peaks (17 and 45 repeats). What can you conclude about this test result?

a) Robert is normal and will not develop Huntington Disease
b) Robert is at risk for developing Huntington Disease but there is a good chance that he will not develop the disease.
c) Robert is almost certain to develop Huntington Disease *
d) Robert is not likely to develop Huntington Disease but his daughter, Andrea, may develop the disease.
e) The test is inconclusive

7–8C) (10 points) Imagine that Robert decides to have the genetic test for Huntington Disease. The report shows two peaks (38 and 19 repeats). What can you conclude about this test result?

a) Robert is normal and will not develop Huntington Disease
b) Robert is at risk for developing Huntington Disease but there is a good chance that he will not develop the disease. *
c) Robert is almost certain to develop Huntington Disease
d) Robert is not likely to develop Huntington Disease but his daughter, Andrea, may develop the disease.
e) The test is inconclusive

7–8D) (10 points) Imagine that Robert decides to have the genetic test for Huntington Disease. The report shows two peaks (30 and 19 repeats). What can you conclude about this test result?

a) Robert is normal and will not develop Huntington Disease
b) Robert is at risk for developing Huntington Disease but there is a good chance that he will not develop the disease.
c) Robert is almost certain to develop Huntington Disease
d) Robert is not likely to develop Huntington Disease but his daughter, Andrea, may develop the disease. *
e) The test is inconclusive

7–8E) (10 points) Imagine that Robert decides to have the genetic test for Huntington Disease. The report shows one peak (17 repeats). What can you conclude about this test result?

a) Robert is normal and will not develop Huntington Disease
b) Robert is at risk for developing Huntington Disease but there is a good chance that he will not develop the disease.
c) Robert is almost certain to develop Huntington Disease
d) Robert is not likely to develop Huntington Disease but his daughter, Andrea, may develop the disease.
e) The test is inconclusive *

9A) (5 points) Which of the following federal legislations prevents employer-based group health insurance plans from canceling policies for individual employees that test positive for a genetic disease?

a) Americans with Disabilities Act (ADA) of 1990
b) Genetic Information Non-Discrimination Act of 2003
c) Health Insurance Portability and Accountability Act (HIPAA) of 1996 *
d) US Patriot Act of 2001
e) None of the above

9B) (5 points) Which of the following federal legislations currently prevents employers from firing employees that test positive for a genetic disease but are as of yet asymptomatic for that disease?

a) Americans with Disabilities Act (ADA) of 1990
b) Genetic Information Non-Discrimination Act of 2003
c) Health Insurance Portability and Accountability Act (HIPAA) of 1996
d) US Patriot Act of 2001
e) None of the above *

9C) (5 points) Which of the following federal legislations has provisions that would prevent employers from firing employees that test positive for a genetic disease but are as of yet asymptomatic for that disease?

a) Americans with Disabilities Act (ADA) of 1990
b) Genetic Information Non-Discrimination Act of 2003 *
c) Health Insurance Portability and Accountability Act (HIPAA) of 1996
d) US Patriot Act of 2001
e) None of the above

10A) (10 points) Based on current Federal laws, which of the following statements is ***not*** true about Robert's relationship with the insurance company that carries group insurance for his employer?

a) If Robert is found to have the Huntington Disease defect the insurance company may not consider it to be a preexisting condition and thus exclude him from the group.
b) His insurance may choose to charge his group a higher premium if he is found to have the Huntington Disease defect.
c) If Robert is found to have the Huntington Disease defect his company may not charge Robert a higher premium for insurance than other members of his group.
d) His insurance company may not require Robert to take a genetic test *
e) The insurance company may not exclude Robert from the group plan based on information that he carries the Huntington Disease defect.

10B) (10 points) Which of the following statements is true about Robert's relationship with the insurance company that carries group insurance for his employer?

a) If Robert is found to have the Huntington Disease defect the insurance company may consider it to be a preexisting condition and thus exclude him from the group

b) His insurance may choose to charge his group a higher premium if he is found to have the Huntington Disease defect. *

c) If Robert is found to have the Huntington Disease defect his company may charge Robert a higher premium for insurance than other members of his group.

d) His insurance company may not require Robert to take a genetic test

e) The insurance company may exclude Robert from the group plan based on information that he carries the Huntington Disease defect.

11A) (10 points) Under which of the circumstances below would a genetic test not be allowed?

a) The individual is a minor (under age 18) *

b) The individual's sibling strongly opposes genetic testing

c) An unborn fetus (prenatal testing)

d) Testing of an embryo prior to implantation (in vitro fertilization)

e) None of the above

11B) (10 points) Imagine that you are the genetic counselor that a client has come to with regard to being tested for a genetic disease. Which of the following information or services would you ***not*** provide?

a) Medical information about the disease

b) Information about the impact of the client's decision on other members of his or her family

c) Make a recommendation about whether the client should or should not take the test *

d) Assistance with interpreting the results of the genetic test

e) None of the above

APPENDIX C

STUDENT EVALUATION QUESTIONS

The following are questions from the end-of-semester evaluations completed by students that are relevant to the research project (dealing with the PBL unit). Despite the promise of extra credit for completing the assignment (in some borderline cases, enough to change a letter grade), we do not get 100% participation in these evaluations (for example, in Fall 2004, we obtained a class participation rate of 73.7%, which is about average). Nevertheless, I feel responses from these evaluations will provide a representative cross-section of attitudes about the PBL unit.

1–5) Rate our effectiveness in accomplishing the following learning objectives:

1) Understand the nature and mode of inheritance of genetic diseases

a) very good
b) good
c) satisfactory
d) poor
e) very poor

2) Gain an appreciation of the human cost of genetic diseases

a) very good
b) good
c) satisfactory
d) poor
e) very poor

3) Understand the principles and technologies used in genetic testing

a) very good
b) good
c) satisfactory
d) poor
e) very poor

4) Gain an appreciation of ethical, legal, and social issues associated with genetic testing

a) very good
b) good
c) satisfactory
d) poor
e) very poor

5) Develop problem solving skills

a) very good
b) good
c) satisfactory
d) poor
e) very poor

6-11) In the next 6 questions we would like you to rate the effectiveness of the assignments in this component.

6) Assignment 8 – Defining the Issues

a)	very good	**d)**	poor
b)	good	**e)**	very poor
c)	satisfactory		

7) Assignment 9 – Genetic Diseases

a)	very good	**d)**	poor
b)	good	**e)**	very poor
c)	satisfactory		

8) Assignment 10 – Genetic Counseling

a)	very good	**d)**	poor
b)	good	**e)**	very poor
c)	satisfactory		

9) Assignment 11 – Genetic Testing

a)	very good	**d)**	poor
b)	good	**e)**	very poor
c)	satisfactory		

10) Assignment 12 – Describing the Disease

a)	very good	**d)**	poor
b)	good	**e)**	very poor
c)	satisfactory		

11) Assignment 13 – Making a Decision

a)	very good	**d)**	poor
b)	good	**e)**	very poor
c)	satisfactory		

12) Rate the effectiveness of the on-line lectures for achieving the learning objectives of this component:

a)	very good	**d)**	poor
b)	good	**e)**	very poor
c)	satisfactory		

13) Rate the effectiveness of the research/outside reading for achieving the learning objectives of this component:

a)	very good	**d)**	poor
b)	good	**e)**	very poor
c)	satisfactory		

14) Rate the effectiveness of the textbook for achieving the learning objectives of this component:

a)	very good	**d)**	poor
b)	good	**e)**	very poor
c)	satisfactory		

15) What did you like best about Module 3?

16) What did you like least about Module 3?

17) Other comments about Module 3:

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